Section 10

Nervous System

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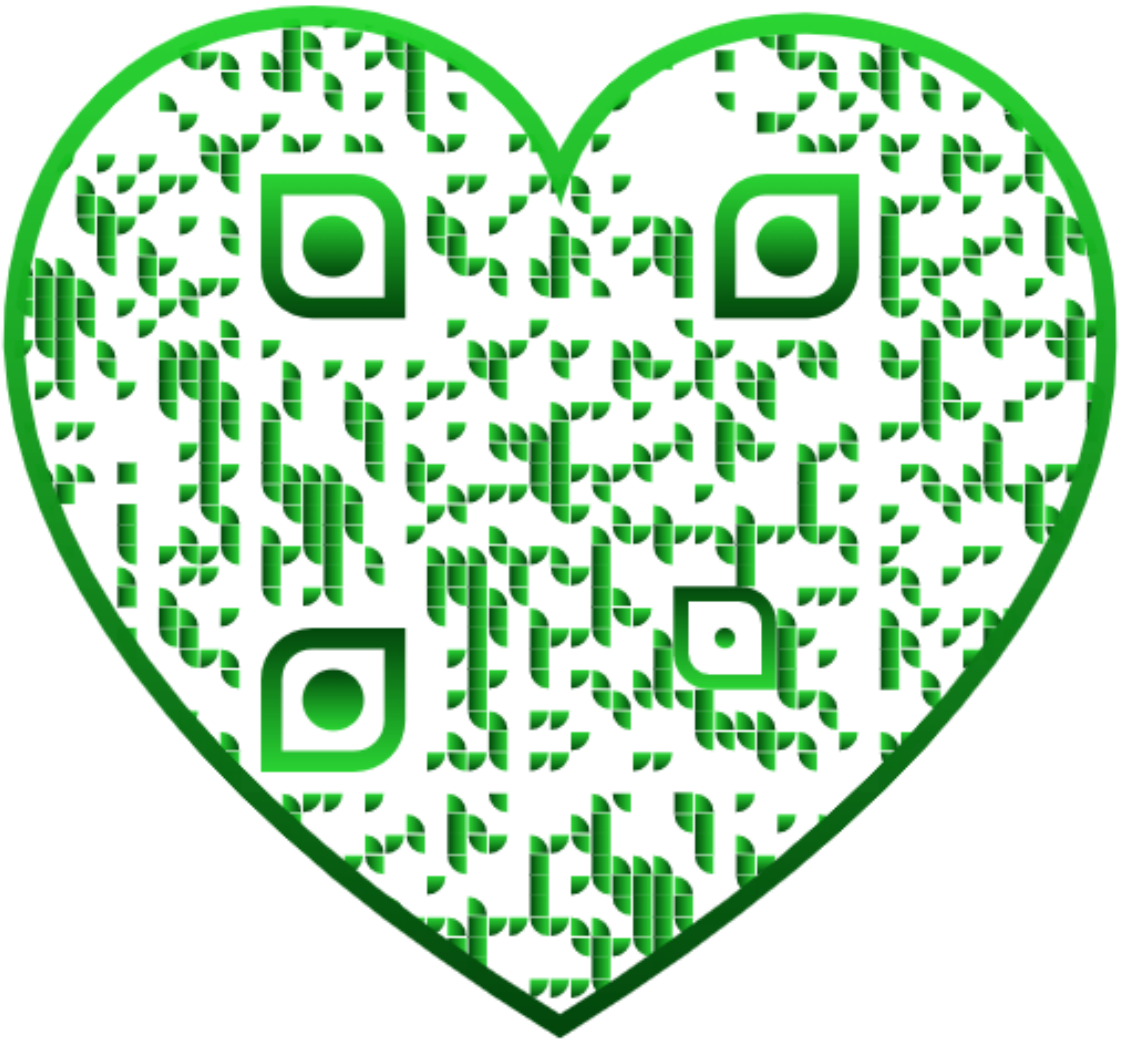

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Introduction to Nervous System

Chapter 133

- DIVISIONS OF NERVOUS SYSTEM
  - CENTRAL NERVOUS SYSTEM
  - PERIPHERAL NERVOUS SYSTEM

DIVISIONS OF NERVOUS SYSTEM

Nervous system controls all the activities of the body. It is quicker than other control system in the body, namely endocrine system. Primarily, nervous system is divided into two parts:

1. Central nervous system
2. Peripheral nervous system.

CENTRAL NERVOUS SYSTEM

Central nervous system (CNS) includes **brain** and **spinal cord.** It is formed by **neurons** and supporting cells called **neuroglia.** Structures of brain and spinal cord are arranged in two layers, namely **gray matter** and **white matter.** Gray matter is formed by nerve cell bodies and the proximal parts of nerve fibers, arising from nerve cell body. White matter is formed by remaining parts of nerve fibers.

In brain, white matter is placed in the inner part and gray matter is placed in the outer part. In spinal cord, white matter is in the outer part and gray matter is in the inner part.

Brain is situated in the **skull.** It is continued as spinal cord in the **vertebral canal** through the **foramen magnum** of the skull bone. Brain and spinal cord are surrounded by three layers of **meninges** called the outer **dura mater,** middle **arachnoid mater** and inner **pia mater.**

The space between arachnoid mater and pia mater is known as **subarachnoid space.** This space is filled with a fluid called cerebrospinal fluid. Brain and spinal cord are actually suspended in the **cerebrospinal fluid.** Important parts of brain and segments of spinal cord are shown in Figure 133.1.

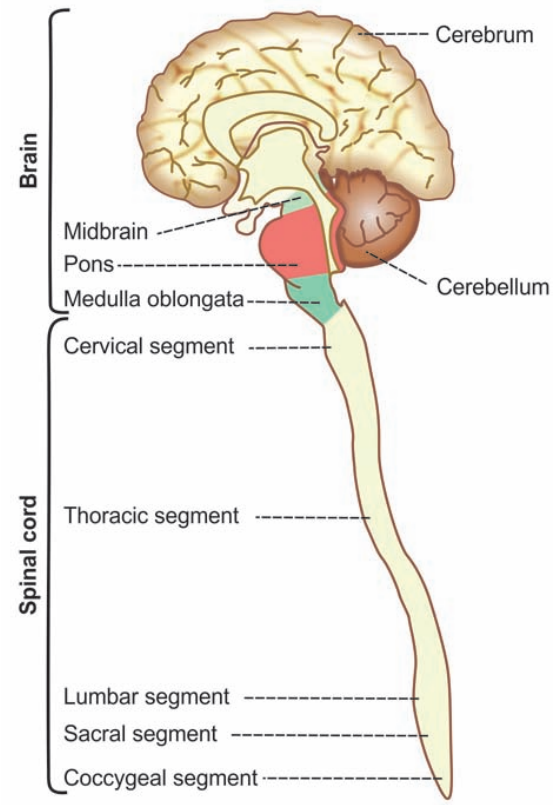

FIGURE 133.1: Parts of central nervous system

Parts of Brain

Brain consists of three major divisions:

1. Prosencephalon

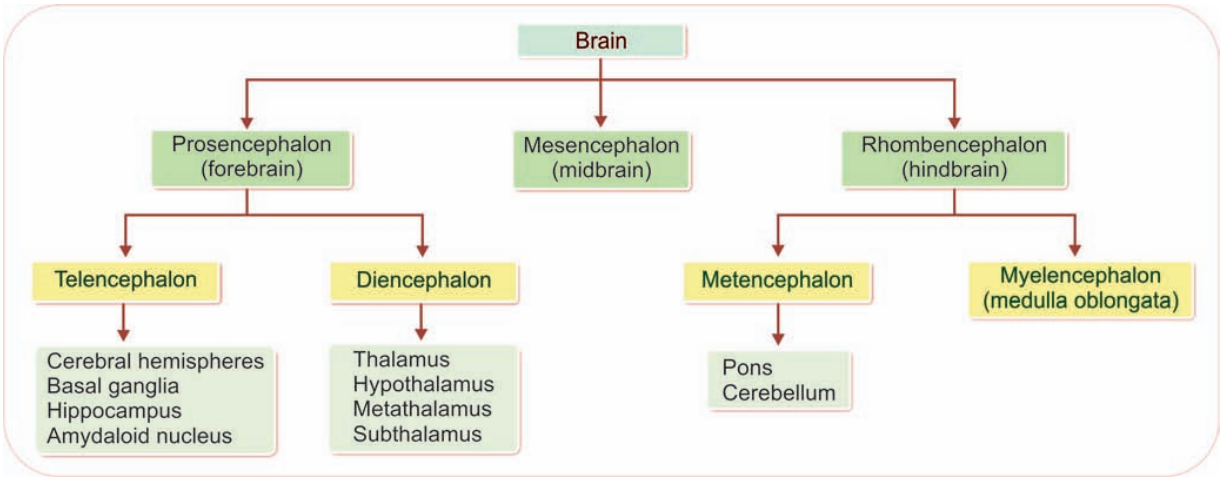

FIGURE 133.2: Parts of brain

2. Mesencephalon
3. Rhombencephalon

1. *Prosencephalon*

Prosencephalon is otherwise known as **forebrain.** It is further divided into two parts:

i. Telencephalon, which includes cerebral hemispheres, basal ganglia, hippocampus and amygdaloid nucleus
ii. Diencephalon, consisting of thalamus, hypothalamus, metathalamus and subthalamus.

2. *Mesencephalon*

Mesencephalon is also known as **midbrain.**

3. *Rhombencephalon*

Rhombencephalon or **hindbrain** is subdivided into two portions:

i. Metencephalon, formed by pons and cerebellum
ii. Myelencephalon or medulla oblongata (Fig. 133.2).

Midbrain, pons and medulla oblongata are together called the brainstem.

■ PERIPHERAL NERVOUS SYSTEM

Peripheral nervous system (PNS) is formed by neurons and their processes present in all regions of the body. It consists of cranial nerves, arising from brain and spinal nerves, arising from the spinal cord. It is again divided into two subdivisions:

1. Somatic nervous system
2. Autonomic nervous system.

1. *Somatic Nervous System*

Somatic nervous system is concerned with **somatic functions.** It includes the nerves supplying the skeletal muscles. Somatic nervous system is responsible for muscular activities and movements of the body (Fig. 133.3).

2. *Autonomic Nervous System*

Autonomic nervous system is concerned with regulation of **visceral** or **vegetative functions.** So, it is otherwise called **vegetative** or **involuntary nervous system.** Autonomic nervous system consists of two divisions, sympathetic division and parasympathetic division.

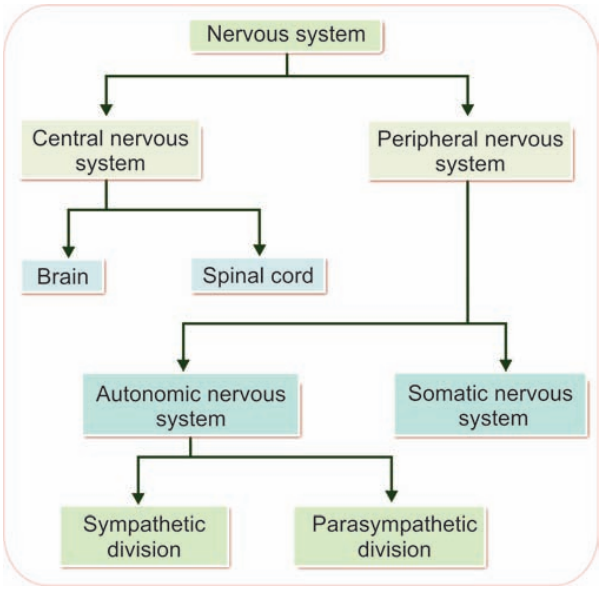

FIGURE 133.3: Organization of nervous system

Chapter 134

Neuron

- INTRODUCTION
- CLASSIFICATION
  - DEPENDING UPON THE NUMBER OF POLES
  - DEPENDING UPON THE FUNCTION
  - DEPENDING UPON THE LENGTH OF AXON
- STRUCTURE
  - NERVE CELL BODY
  - DENDRITE
  - AXON
  - MYELIN SHEATH
  - NEURILEMMA
- NEUROTROPHINS – NEUROTROPHIC FACTORS
  - NERVE GROWTH FACTOR
  - OTHER NEUROTROPHINS

INTRODUCTION

Neuron or **nerve cell** is defined as the structural and functional unit of nervous system. Neuron is similar to any other cell in the body, having nucleus and all the organelles in cytoplasm. However, it is different from other cells by two ways:

1. Neuron has branches or processes called **axon** and **dendrites**
2. Neuron does not have centrosome. So, it cannot undergo division.

CLASSIFICATION OF NEURON

Neurons are classified by three different methods.

A. Depending upon the number of poles
B. Depending upon the function
C. Depending upon the length of axon.

DEPENDING UPON THE NUMBER OF POLES

Based on the number of poles from which the nerve fibers arise, neurons are divided into three types:

1. Unipolar neurons
2. Bipolar neurons
3. Multipolar neurons.

1. *Unipolar Neurons*

Unipolar neurons are the neurons that have only **one pole.** From a single pole, both axon and dendrite arise (Fig. 134.1). This type of nerve cells is present only in embryonic stage in human beings.

2. *Bipolar Neurons*

Neurons with **two poles** are known as bipolar neurons. Axon arises from one pole and dendrites arise from the other pole.

3. *Multipolar Neurons*

Multipolar neurons are the neurons which have **many poles.** One of the poles gives rise to axon and all other poles give rise to dendrites.

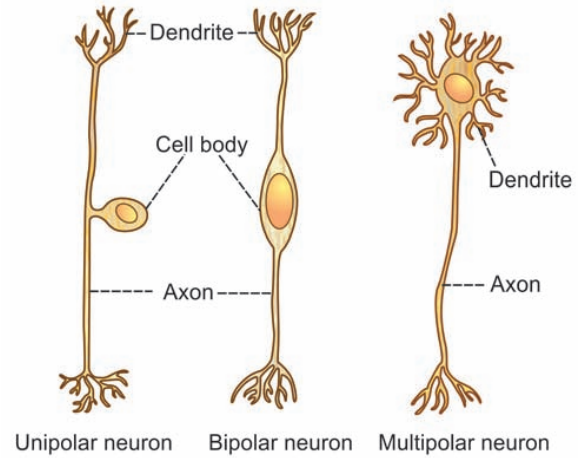

FIGURE 134.1: Types of neuron

■ DEPENDING UPON THE FUNCTION

On the basis of function, nerve cells are classified into two types:

1. Motor or efferent neurons
2. Sensory or afferent neurons.

1. *Motor or Efferent Neurons*

Motor or efferent neurons are the neurons which carry the **motor impulses** from central nervous system to peripheral effector organs like muscles, glands, blood vessels, etc. Generally, each motor neuron has a long axon and short dendrites.

2. *Sensory or Afferent Neurons*

Sensory or afferent neurons are the neurons which carry the **sensory impulses** from periphery to central nervous system. Generally, each sensory neuron has a short axon and long dendrites.

■ DEPENDING UPON THE LENGTH OF AXON

Depending upon the length of axon, neurons are divided into two types:

1. Golgi type I neurons
2. Golgi type II neurons.

1. *Golgi Type I Neurons*

Golgi type I neurons have **long axons.** Cell body of these neurons is in different parts of central nervous system and their axons reach the remote peripheral organs.

2. *Golgi Type II Neurons*

Neurons of this type have **short axons.** These neurons are present in cerebral cortex and spinal cord.

■ STRUCTURE OF NEURON

Neuron is made up of three parts:

1. Nerve cell body
2. Dendrite
3. Axon.

Dendrite and axon form the **processes** of neuron (Fig. 134.2). Dendrites are **short processes** and the axons are **long processes.** Dendrites and axons are usually called **nerve fibers.**

■ NERVE CELL BODY

Nerve cell body is also known as **soma** or **perikaryon.** It is irregular in shape. Like any other cell, it is constituted by a mass of cytoplasm called neuroplasm, which is covered by a cell membrane. The cytoplasm contains a large nucleus, Nissl bodies, neurofibrils, mitochondria and Golgi apparatus. Nissl bodies and neurofibrils are found only in nerve cell and not in other cells.

Nucleus

Each neuron has one nucleus, which is centrally placed in the nerve cell body. Nucleus has one or two prominent nucleoli. Nucleus does not contain centrosome. So, the nerve cell cannot multiply like other cells.

Nissl Bodies

Nissl bodies or **Nissl granules** are small basophilic granules found in cytoplasm of neurons and are named after the discoverer. These bodies are present in soma and dendrite but not in axon and **axon hillock.** Nissl bodies are called **tigroid substances,** since these bodies are responsible for tigroid or spotted appearance of soma after suitable staining. Dendrites are distinguished from axons by the presence of Nissl granules under microscope.

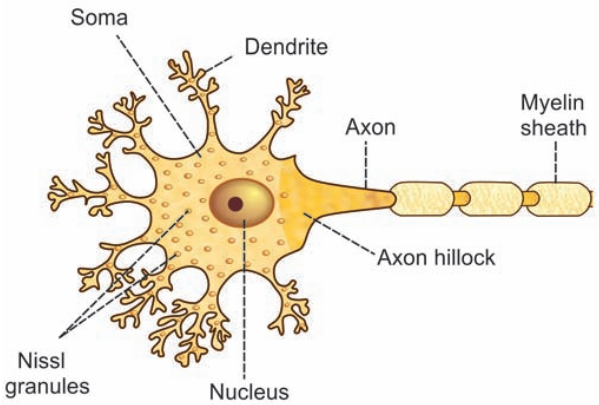

FIGURE 134.2: Structure of a neuron

Nissl bodies are membranous organelles containing ribosomes. So, these bodies are concerned with synthesis of proteins in the neurons. Proteins formed in soma are transported to the axon by axonal flow.

Number of Nissl bodies varies with the condition of the nerve. During fatigue or injury of the neuron, these bodies fragment and disappear by a process called **chromatolysis.** Granules reappear after recovery from fatigue or after regeneration of nerve fibers.

Neurofibrils

Neurofibrils are thread-like structures present in the form of network in the soma and the nerve processes. Presence of neurofibrils is another characteristic feature of the neurons. The neurofibrils consist of microfilaments and microtubules.

Mitochondria

Mitochondria are present in soma and in axon. As in other cells, here also mitochondria form the powerhouse of the nerve cell, where ATP is produced (Chapter 1).

Golgi Apparatus

Golgi apparatus of nerve cell body is similar to that of other cells. It is concerned with processing and packing of proteins into granules (Chapter 1).

■ DENDRITE

Dendrite is the **branched process** of neuron and it is branched repeatedly. Dendrite may be present or absent. If present, it may be one or many in number. Dendrite has Nissl granules and neurofibrils.

Dendrite transmits impulses towards the nerve cell body. Usually, the dendrite is shorter than axon.

■ AXON

Axon is the **longer process** of nerve cell. Each neuron has only one axon. Axon arises from axon hillock of the nerve cell body and it is devoid of Nissl granules. Axon extends for a long distance away from the nerve cell body. Length of longest axon is about 1 meter.

Axon transmits impulses away from the nerve cell body.

Organization of Nerve

Each nerve is formed by many bundles or groups of nerve fibers. Each bundle of nerve fibers is called a **fasciculus.**

Coverings of Nerve

The whole nerve is covered by tubular sheath, which is formed by a areolar membrane. This sheath is called **epineurium.** Each fasciculus is covered by **perineurium** and each nerve fiber (axon) is covered by **endoneurium** (Fig. 134.3).

Internal Structure of Axon – Axis Cylinder

Axon has a long central core of cytoplasm called **axoplasm.** Axoplasm is covered by the tubular sheath-like membrane called **axolemma.** Axolemma is the continuation of the cell membrane of nerve cell body. Axoplasm along with axolemma is called the **axis cylinder** of the nerve fiber (Fig. 134.4).

Axoplasm contains mitochondria, neurofibrils and axoplasmic vesicles. Because of the absence of Nissl bodies in the axon, proteins necessary for the nerve fibers are synthesized in the soma and not in axoplasm. After synthesis, the protein molecules are transported from soma to axon, by means of **axonal flow.** Some neurotransmitter substances are also transported by axonal flow from soma to axon.

Axis cylinder of the nerve fiber is covered by a membrane called **neurilemma** (see below).

Non-myelinated Nerve Fiber

Nerve fiber described above is the non-myelinated nerve fiber, which is not covered by myelin sheath.

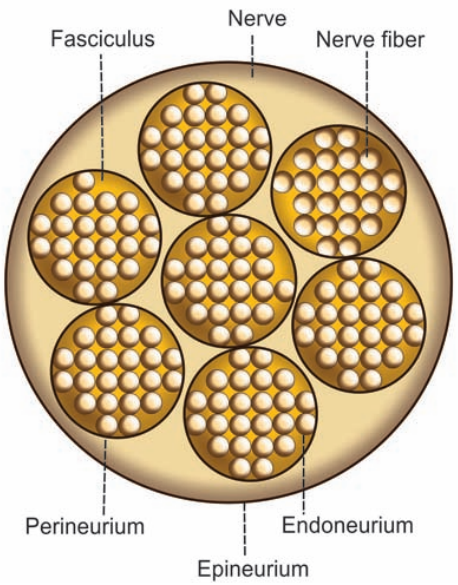

FIGURE 134.3: Cross section of a nerve

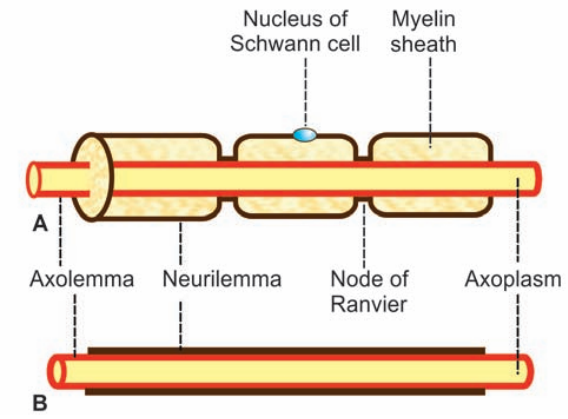

FIGURE 134.4: A. Myelinated nerve fiber; **B.** Non-myelinated nerve fiber.

Myelinated Nerve Fiber

Nerve fiber which is insulated by myelin sheath is called myelinated nerve fibers.

■ MYELIN SHEATH

Myelin sheath is a thick lipoprotein sheath that insulates the myelinated nerve fiber. Myelin sheath is not a continuous sheath. It is absent at regular intervals. The area where myelin sheath is absent is called **node of Ranvier.** Segment of the nerve fiber between two nodes is called **internode.** Myelin sheath is responsible for white color of nerve fibers.

Chemistry of Myelin Sheath

Myelin sheath is formed by concentric layers of proteins, alternating with lipids. The lipids are cholesterol, lecithin and cerebroside (sphingomyelin).

Formation of Myelin Sheath – Myelinogenesis

Formation of myelin sheath around the axon is called the myelinogenesis. It is formed by **Schwann cells** in neurilemma. In the peripheral nerve, the myelinogenesis starts at 4th month of intrauterine life. It is completed only in the second year after birth.

Before myelinogenesis, Schwann cells of the neurilemma are very close to axolemma, as in the case of unmyelinated nerve fiber. The membrane of the Schwann cell is double layered.

Schwann cells wrap up and rotate around the axis cylinder in many concentric layers. The concentric layers fuse to produce myelin sheath but cytoplasm of the cells is not deposited. Outermost membrane of Schwann cell remains as neurilemma. Nucleus of these cells remains in between myelin sheath and neurilemma.

Functions of Myelin Sheath

1. *Faster conduction*

Myelin sheath is responsible for faster conduction of impulse through the nerve fibers. In myelinated nerve fibers, the impulses jump from one node to another node. This type of transmission of impulses is called **saltatory conduction** (Chapter 136).

2. *Insulating capacity*

Myelin sheath has a high insulating capacity. Because of this quality, myelin sheath restricts the nerve impulse within single nerve fiber and prevents the stimulation of neighboring nerve fibers.

■ NEURILEMMA

Neurilemma is a thin membrane, which surrounds the axis cylinder. It is also called **neurilemmal sheath** or **sheath of Schwann.** It contains Schwann cells, which have flattened and elongated nuclei. Cytoplasm is thin and modified to form the thin sheath of neurilemma.

One nucleus is present in each internode of the axon. Nucleus is situated between myelin sheath and neurilemma.

In non-myelinated nerve fiber, the neurilemma surrounds axolemma continuously. In myelinated nerve fiber, it covers the myelin sheath. At the node of Ranvier (where myelin sheath is absent), neurilemma invaginates and runs up to axolemma in the form of a finger-like process.

Functions of Neurilemma

In non-myelinated nerve fiber, the neurilemma serves as a covering membrane. In myelinated nerve fiber, it is necessary for the formation of myelin sheath (myelinogenesis). Neurilemma is absent in central nervous system. So, the neuroglial cells called **oligodendroglia** are responsible for myelinogenesis in central nervous system.

■ NEUROTROPHINS – NEUROTROPHIC FACTORS

Neurotrophins or neurotrophic factors are the protein substances, which play an important role in growth and functioning of nervous tissue.

Source of Secretion

Neurotrophins are secreted by many tissues in the body, particularly muscles, neuroglial cells called astrocytes and neurons.

Functions

Neurotrophins:

1. Facilitate initial growth and development of nerve cells in central and peripheral nervous system
2. Promote survival and repair of the nerve cells
3. Play an important role in the maintenance of nervous tissue and neural transmission.

Recently, it is found that neurotrophins are capable of making the damaged neurons regrow their processes *in vitro* and in animal models. This indicates the possibilities of reversing the devastating symptoms of nervous disorders like **Parkinson disease** and **Alzheimer disease.**

Commercial preparations of neurotrophins are used for the treatment of some neural diseases.

Mode of Action

Neurotrophins act via neurotrophin receptors, which are situated at the nerve terminals and nerve cell body. Neurotrophins bind with receptors and initiate the phosphorylation of tyrosine kinase.

Types

Nerve growth factor (NGF) was the first protein substance identified as neurotrophin. Now, many types of neurotophic factors are identified.

■ NERVE GROWTH FACTOR

Nerve growth factor (NGF) is a neurotrophin found in many peripheral tissues.

Chemistry

NGF is a peptide with 118 amino acids. Each molecule of NGF is made up of two α-subunits, two β-subunits and two γ-subunits. Only the β-subunits have nerve growth-stimulating activity.

Functions

1. NGF promotes early growth and development of neurons. Its major action is on sympathetic and sensory neurons, particularly the neurons concerned with pain. Because of its major action on sympathetic neurons, it is also called **sympathetic NGF.** NGF also promotes the growth of cholinergic neurons in cerebral hemispheres.
2. Commercial preparation of NGF extracted from snake venom and submaxillary glands of male mouse is used to treat sympathetic neuron diseases.
3. NGF plays an important role in treating many nervous disorders such as Alzheimer disease, neuron degeneration in aging and neuron regeneration in spinal cord injury.

■ OTHER NEUROTROPHINS

1. *Brain-derived Neurotrophic Growth Factor*

Brain-derived neurotrophic growth factor (BDGF) was first discovered in the brain of pig. Now it is found in human brain and human sperm. BDGF promotes the survival of sensory and motor neurons, arising from embryonic neural crest. It also protects the sensory neurons in peripheral nervous system and motor neurons of pyramidal system. It enhances the growth of cholinergic, dopaminergic and optic nerves. It is suggested that BDGF may regulate synaptic transmission.

Commercial preparation is used to treat **motor neuron diseases.**

2. *Ciliary Neurotrophic Factor (CNTF)*

CNTF is secreted in peripheral nerves, ocular muscles and cardiac muscle. It protects neurons of ciliary ganglion and motor neurons.

3. *Glial Cell Line-derived Neurotrophic Factor (GNDF)*

GDNF is found in neuroglial cells. It has a potent protective action on dopaminergic neurons. It is used for the treatment of **Parkinson disease.**

4. *Fibroblast Growth Factor (FGF)*

FGF was first discovered as growth factor promoting the fibroblastic growth. It is also known to protect the neurons.

5. *Neurotrophin-3 (NT-3)*

Neurotrophin-3 (NT-3) acts on γ-motor neurons, sympathetic neurons and neurons from sensory organs. It also regulates the release of neurotransmitter from neuromuscular junction.

NT-3 is useful for the treatment of motor axonal neuropathy and diabetic neuropathy.

Recently, few more substances belonging to the neurotrophin family such as NT-4, NT-5 and leukemia-inhibiting factor are identified. NT-4 and NT-5 act on sympathetic neurons, sensory neurons and motor neurons.

Classification of Nerve Fibers

Chapter 135

- BASIS OF CLASSIFICATION
  - DEPENDING UPON STRUCTURE
  - DEPENDING UPON DISTRIBUTION
  - DEPENDING UPON ORIGIN
  - DEPENDING UPON FUNCTION
  - DEPENDING UPON SECRETION OF NEUROTRANSMITTER
  - DEPENDING UPON DIAMETER AND CONDUCTION OF IMPULSE

BASIS OF CLASSIFICATION

Nerve fibers are classified by six different methods. The basis of classification differs in each method. Different methods of classification are listed in Box 135.1.

BOX 135.1: Different methods to classify nerve fibers

Classification of nerve fibers
1. Depending upon structure
2. Depending upon distribution
3. Depending upon origin
4. Depending upon function
5. Depending upon secretion of neurotransmitter
6. Depending upon diameter and conduction of impulse (Erlanger-Gasser classification)

1. DEPENDING UPON STRUCTURE

Based on structure, nerve fibers are classified into two types:

i. *Myelinated Nerve Fibers*

Myelinated nerve fibers are the nerve fibers that are covered by **myelin sheath.**

ii. *Non-myelinated Nerve Fibers*

Non-myelinated nerve fibers are the nerve fibers which are not covered by myelin sheath.

2. DEPENDING UPON DISTRIBUTION

Nerve fibers are classified into two types, on the basis of distribution:

i. *Somatic Nerve Fibers*

Somatic nerve fibers supply the **skeletal muscles** of the body.

ii. *Visceral or Autonomic Nerve Fibers*

Autonomic nerve fibers supply the various **internal organs** of the body.

3. DEPENDING UPON ORIGIN

On the basis of origin, nerve fibers are divided into two types:

i. *Cranial Nerve Fibers*

Nerve fibers arising from **brain** are called cranial nerve fibers.

ii. *Spinal Nerve Fibers*

Nerve fibers arising from **spinal cord** are called spinal nerve fibers.

4. DEPENDING UPON FUNCTION

Functionally, nerve fibers are classified into two types:

i. *Sensory Nerve Fibers*

Sensory nerve fibers carry sensory impulses from different parts of the body to the central nervous system. These nerve fibers are also known as **afferent nerve fibers.**

ii. *Motor Nerve Fibers*

Motor nerve fibers carry motor impulses from central nervous system to different parts of the body. These nerve fibers are also called **efferent nerve fibers.**

■ 5. DEPENDING UPON SECRETION OF NEUROTRANSMITTER

Depending upon the neurotransmitter substance secreted, nerve fibers are divided into two types:

i. *Adrenergic Nerve Fibers*

Adrenergic nerve fibers secrete **noradrenaline.**

ii. *Cholinergic Nerve Fibers*

Cholinergic nerve fibers secrete **acetylcholine.**

■ 6. DEPENDING UPON DIAMETER AND CONDUCTION OF IMPULSE (ERLANGER-GASSER CLASSIFICATION)

Erlanger and Gasser classified the nerve fibers into three major types, on the basis of **diameter** (thickness) of the fibers and velocity of **conduction of impulses:**

TABLE 135.1: Types of nerve fibers

Type	Diameter (μ)	Velocity of conduction (meter/second)
A alpha	12 to 24	70 to 120
A beta	6 to 12	30 to 70
A gamma	5 to 6	15 to 30
A delta	2 to 5	12 to 15
B	1 to 2	3 to 10
C	< 1.5	0.5 to 2

i. Type A nerve fibers
ii. Type B nerve fibers
iii. Type C nerve fibers.

Among these fibers, type A nerve fibers are the thickest fibers and type C nerve fibers are the thinnest fibers. Type C fibers are also known as Type IV fibers. Except type C fibers, all the nerve fibers are myelinated.

Type A nerve fibers are divided into four types:

a. Type A alpha or Type I nerve fibers
b. Type A beta or Type II nerve fibers
c. Type A gamma nerve fibers
d. Type A delta or Type III nerve fibers.

Velocity of Impulse

Velocity of impulse through a nerve fiber is directly proportional to the thickness of the fiber. Different types of nerve fibers along with diameter and velocity of conduction are given in Table 135.1.

Chapter 136

Properties of Nerve Fibers

- EXCITABILITY
  - ACTION POTENTIAL OR NERVE IMPULSE
  - ELECTROTONIC POTENTIAL OR LOCAL POTENTIAL
  - VOLTAGE CLAMPING
- CONDUCTIVITY
  - MECHANISM OF CONDUCTION OF ACTION POTENTIAL
  - CONDUCTION THROUGH MYELINATED NERVE FIBER – SALTATORY CONDUCTION
- REFRACTORY PERIOD
  - TYPES OF REFRACTORY PERIOD
- SUMMATION
- ADAPTATION
- INFATIGABILITY
- ALL-OR-NONE LAW

EXCITABILITY

Excitability is defined as the **physiochemical change** that occurs in a tissue when stimulus is applied.

Stimulus is defined as an external agent, which produces excitability in the tissues. Different types of stimulus, qualities of stimulus and strength-duration curve are explained in Chapter 30. **Chronaxie** is an important parameter to determine the condition of nerve fiber. Clinically, the damage of nerve fiber is determined by measuring the chronaxie. It is measured by chronaxie meter.

Nerve fibers have a low threshold for excitation than the other cells.

Response Due to Stimulation of Nerve Fiber

When a nerve fiber is stimulated, based on the strength of stimulus, two types of response develop:

1. *Action potential or nerve impulse*

Action potential develops in a nerve fiber when it is stimulated by a stimulus with adequate strength. Adequate strength of stimulus, necessary for producing the action potential in a nerve fiber is known as **threshold** or **minimal stimulus.** Action potential is propagated.

2. *Electrotonic potential or local potential*

When the stimulus with **subliminal strength** is applied, only electrotonic potential develops and the action potential does not develop. Electrotonic potential is non-propagated.

Cathelectrotonic and Anelectrotonic Potentials

While recording electrical potential in a nerve fiber, two electrodes, namely **cathode** and **anode** are used. The potential change that is produced at cathode is called cathelectrotonic potential. The potential that is developed at anode is known as anelectrotonic potential.

Only the cathelectrotonic potential can be transformed into electrotonic potential or action potential.

ACTION POTENTIAL OR NERVE IMPULSE

Action potential in a nerve fiber is similar to that in a muscle, except for some minor differences (Table 136.1). Action potential in a skeletal muscle fiber is described in Chapter 31.

TABLE 136.1: Differences between electrical potential in nerve fiber and muscle fiber

Event	Nerve fiber	Skeletal muscle fiber
Resting membrane potential	–70 mV	–90 mV
Firing level	–55 mV	–75 mV
End of depolarization	+35 mV	+55 mV

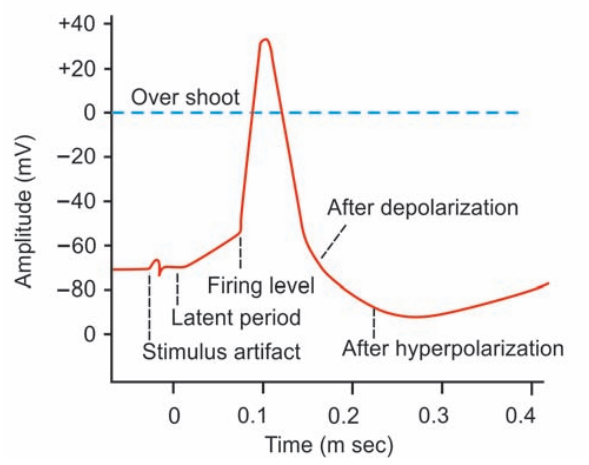

FIGURE 136.1: Action potential in nerve fiber

Resting membrane potential in the nerve fiber is –70 mV. The firing level is at –55 mV. Depolarization ends at +35 mV (Fig. 136.1). Usually, the action potential starts in the initial segment of nerve fiber.

Properties of Action Potential

Properties of action potential are given in Chapter 31.

■ ELECTROTONIC POTENTIAL OR LOCAL POTENTIAL

Electrotonic potential or local potential is a non-propagated **local response** that develops in the nerve fiber when a subliminal stimulus is applied. Subliminal or subthreshold stimulus does not produce action potential. But, it alters the resting membrane potential and produces **slight depolarization** for about 7 mV. This slight depolarized state is called electrotonic potential. Firing level is reached only if depolarization occurs up to 15 mV. Then only action potential can develop.

Electrotonic potential is a **graded potential** (Refer to Chapter 31).

Properties of Electrotonic Potential

1. Electrotonic potential is **non-propagated**
2. It does not obey **all-or-none law.** If the intensity of the stimulus is increased gradually every time, there is increase in the amplitude till the firing level is reached, i.e. at 15 mV.

■ VOLTAGE CLAMPING

The term 'voltage clamping' refers to an experimental method that uses electrodes to alter and control the membrane potential. Voltage clamp technique is a modified **patch clamp technique** (Chapter 31) applied to nerve fibers. It is used to measure the ionic current across the membrane of nerve fiber by fixing the membrane potential at a desired voltage.

Principle of Voltage Clamping

Normally, the voltage-gated ion channels open and close in response to positive or negative charge within the cell. In order to understand the movement of ions across the membrane (ion flux), it would be necessary to eliminate the other variable, i.e. the differences in the membrane potential. It is because of two reasons:

1. Both the ion flux and membrane potential are interrelated
2. Differences in membrane potential would lead to differences in ion flux.

So the membrane potential is fixed (clamped) at a specific level by using voltage clamp. It allows study of the ion flux through ionic channels at specific membrane potentials.

Equipment for Voltage Clamping

Voltage clamp equipment has three units:

1. Recording amplifier
2. Current generator
3. Feedback amplifier.

1. Recording amplifier measures the voltage of membrane potential. Two recording electrodes namely, the **extracelluar electrode** and **intracellular electrode** are connected to this amplifier. Extracellular electrode is placed on the outer surface of the nerve membrane and the intracellular electrode is inserted into the nerve fiber.
2. Current generator or **signal generator** is used to control the resting membrane potential of the nerve fiber. The current signals generated by this instrument are passed into the nerve fiber through a current electrode.

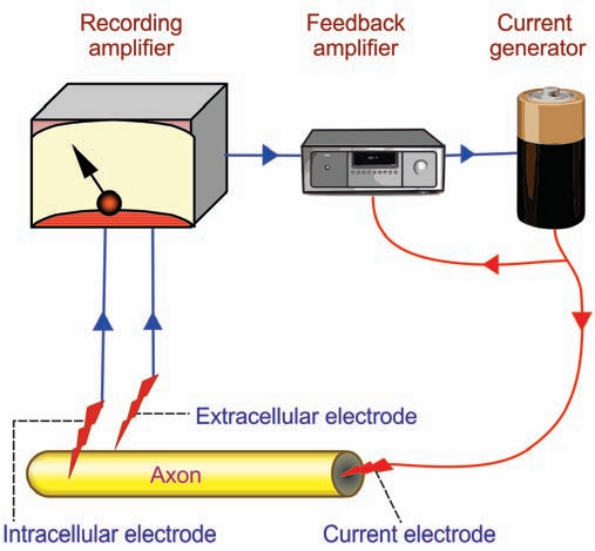

FIGURE 136.2: Voltage clamping

3. Feedback amplifier receives feedback inputs from recording amplifier and current generator and accordingly modifies the current signals that are sent into the nerve fiber (Fig. 136.2).

Thus, by voltage clamping, it is possible to maintain the constant membrane potential at a desired voltage.

Nerve Fibers Used for Voltage Clamping

Earlier, the voltage clamp tests were done on the giant axon of the squid ***Loligo,*** whose size facilitates such tests. Then the investigations were done on the neurons of small mammals. Nowadays, the tests are done on the human nerve fibers obtained from surgical procedures.

■ CONDUCTIVITY

Conductivity is the ability of nerve fibers to transmit the impulse from the area of stimulation to the other areas. Action potential is transmitted through the nerve fiber as nerve impulse. Normally in the body, the action potential is transmitted through the nerve fiber in only one direction. However, in experimental conditions when, the nerve is stimulated, the action potential travels through the nerve fiber in either direction.

■ MECHANISM OF CONDUCTION OF ACTION POTENTIAL

Depolarization occurs first at the site of stimulation in the nerve fiber. It causes depolarization of the neighboring areas. Like this, depolarization travels throughout the nerve fiber. Depolarization is followed by repolarization.

■ CONDUCTION THROUGH MYELINATED NERVE FIBER – SALTATORY CONDUCTION

Saltatory conduction is the form of conduction of nerve impulse in which, the impulse jumps from **one node to another.** Conduction of impulse through a myelinated nerve fiber is about 50 times faster than through a non-myelinated fiber. It is because the action potential jumps from one node to another node of Ranvier instead of travelling through the entire nerve fiber (Fig. 136.3).

Mechanism of Saltatory Conduction

Myelin sheath is not permeable to ions. So, the entry of sodium from extracellular fluid into nerve fiber occurs only in the node of Ranvier, where the myelin sheath is absent. It causes depolarization in the node and not in the internode. Thus, depolarization occurs at successive

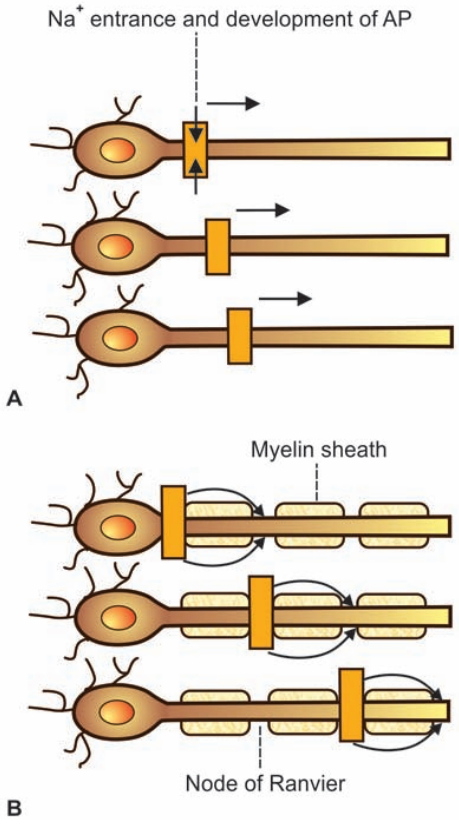

FIGURE 136.3: Mode of conduction through nerve fibers A. Non-myelinated nerve fiber: continuous conduction. B. Myelinated nerve fiber: saltatory conduction (impulse jumps from node to node). AP = Action potential.

nodes. So, the action potential jumps from one node to another. Hence, it is called saltatory conduction (saltare = jumping).

REFRACTORY PERIOD

Refractory period is the period at which the nerve does not give any response to a stimulus.

TYPES OF REFRACTORY PERIOD

Refractory period is of two types:

1. *Absolute Refractory Period*

Absolute refractory period is the period during which the nerve does not show any response at all, whatever may be the strength of stimulus.

2. *Relative Refractory Period*

It is the period, during which the nerve fiber shows response, if the strength of stimulus is increased to maximum.

Absolute refractory period corresponds to the period from the time when firing level is reached till the time when one third of repolarization is completed. Relative refractory period extends through rest of the repolarization period.

SUMMATION

When one subliminal stimulus is applied, it does not produce any response in the nerve fiber because, the subliminal stimulus is very weak. However, if two or more subliminal stimuli are applied within a short interval of about 0.5 millisecond, the response is produced. It is because the subliminal stimuli are summed up together to become strong enough to produce the response. This phenomenon is known as summation.

ADAPTATION

While stimulating a nerve fiber continuously, the excitability of the nerve fiber is greater in the beginning. Later the response decreases slowly and finally the nerve fiber does not show any response at all. This phenomenon is known as adaptation or **accommodation.**

Cause for Adaptation

When a nerve fiber is stimulated continuously, depolarization occurs continuously. Continuous depolarization inactivates the sodium pump and increases the efflux of potassium ions.

INFATIGABILITY

Nerve fiber cannot be fatigued, even if it is stimulated continuously for a long time. The reason is that nerve fiber can conduct only one action potential at a time. At that time, it is completely refractory and does not conduct another action potential.

ALL-OR-NONE LAW

All-or-none law states that when a nerve is stimulated by a stimulus it gives maximum response or does not give response at all. Refer Chapter 90 for more details on all-or-none law.

Degeneration and Regeneration of Nerve Fibers

Chapter 137

- INTRODUCTION
- DEGREES OF INJURY
  - FIRST DEGREE
  - SECOND DEGREE
  - THIRD DEGREE
  - FOURTH DEGREE
  - FIFTH DEGREE
- DEGENERATIVE CHANGES IN THE NEURON
  - WALLERIAN DEGENERATION
  - RETROGRADE DEGENERATION
  - TRANSNEURONAL DEGENERATION
- REGENERATION OF NERVE FIBER
  - CRITERIA FOR REGENERATION
  - STAGES OF REGENERATION

INTRODUCTION

When a nerve fiber is injured, various changes occur in the nerve fiber and nerve cell body. All these changes are together called the **degenerative changes.**

Causes for Injury

Injury to nerve fiber occurs due to following causes:

1. Obstruction of blood flow
2. Local injection of toxic substances
3. Crushing of nerve fiber
4. Transection of nerve fiber.

DEGREES OF INJURY

Sunderland had classified the injury to nerve fibers into five categories depending upon the order of severity.

FIRST DEGREE

First degree injury is the most common type of injury to the nerves. It is caused by **applying pressure** over a nerve for a short period leading to occlusion of blood flow and hypoxia.

By first degree of injury, axon is not destroyed but mild demyelination occurs. It is not a true degeneration. Axon looses the function temporarily for a short time, which is called conduction block. The function returns within few hours to few weeks. First degree of injury is called **Seddon neuropraxia.**

SECOND DEGREE

Second degree is due to the **prolonged severe pressure,** which causes **Wallerian degeneration** (see below). However, the endoneurium is intact. Repair and restoration of function take about 18 months. Second degree of injury is called **axonotmesis.**

THIRD DEGREE

In this case, the **endoneurium** is interrupted. Epineurium and perineurium are intact. After degeneration, the recovery is slow and poor or incomplete. Third, fourth and fifth degrees of injury are called **neurotmesis.**

FOURTH DEGREE

This type of injury is more severe. Epineurium and perineurium are also interrupted. Fasciculi of nerve fibers are disturbed and disorganized. Regeneration is poor or incomplete.

FIFTH DEGREE

Fifth degree of injury involves **complete transaction** of the nerve trunk with loss of continuity. Useful regeneration is not possible unless the cut ends are rearranged and approximated quickly by surgery.

DEGENERATIVE CHANGES IN THE NEURON

Degeneration refers to deterioration or impairment or pathological changes of an injured tissue. When a peripheral nerve fiber is injured, the degenerative changes occur in the nerve cell body and the nerve fiber of same neuron and the adjoining neuron.

Accordingly, degenerative changes are classified into three types:

1. Wallerian degeneration
2. Retrograde degeneration
3. Transneuronal degeneration.

WALLERIAN DEGENERATION OR ORTHOGRADE DEGENERATION

Wallerian degeneration is the pathological change that occurs in the distal cut end of nerve fiber (axon). It is named after the discoverer **Waller.** It is also called orthograde degeneration. Wallerian degeneration starts within 24 hours of injury. Change occurs throughout the length of distal part of nerve fiber simultaneously.

Changes in Nerve

i. Axis cylinder swells and breaks up into small pieces. After few days, the broken pieces appear as debris in the space occupied by axis cylinder (Fig. 137.1).
ii. Myelin sheath is slowly disintegrated into fat droplets. The changes in myelin sheath occur from 8th to 35th day.
iii. Neurilemmal sheath is unaffected, but the Schwann cells multiply rapidly. Macrophages invade from outside and remove the debris of axis cylinder and fat droplets of disintegrated myelin sheath. So, the neurilemmal tube becomes empty. Later it is filled by the cytoplasm of Schwann cell. All these changes take place for about 2 months from the day of injury.

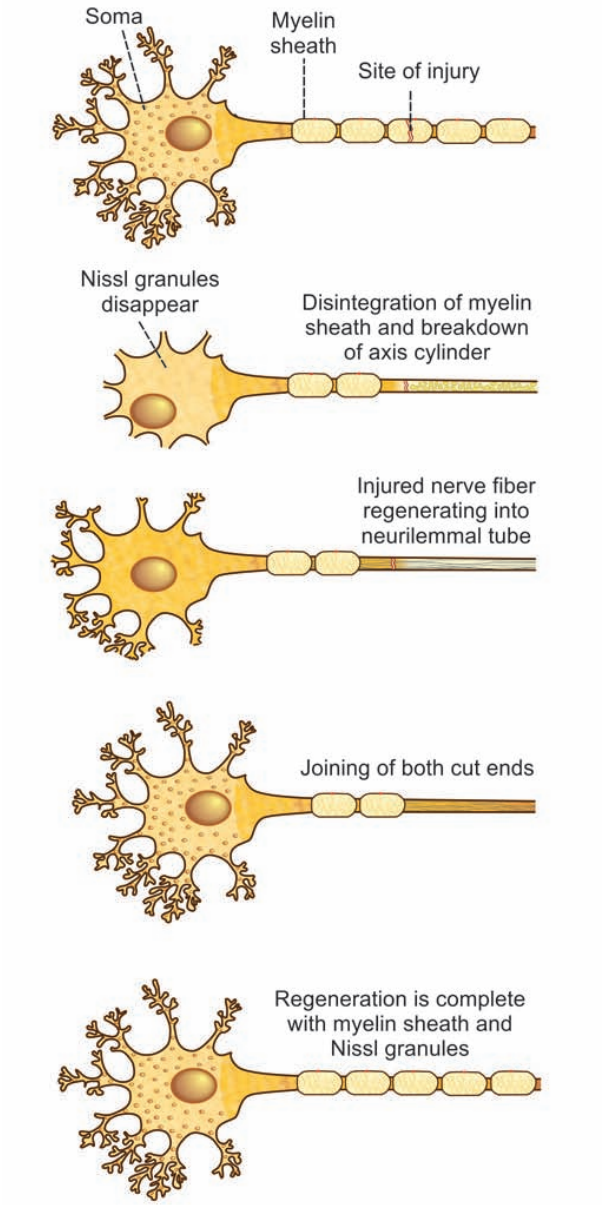
Soma
Myelin sheath
Site of injury
Nissl granules disappear
Disintegration of myelin sheath and breakdown of axis cylinder
Injured nerve fiber regenerating into neurilemmal tube
Joining of both cut ends
Regeneration is complete with myelin sheath and Nissl granules

FIGURE 137.1: Degeneration and regeneration of nerve fiber

RETROGRADE DEGENERATION

Retrograde degeneration is the pathological changes, which occur in the nerve cell body and axon proximal to the cut end.

Changes in Nerve Cell Body

Changes in the nerve cell body commence within 48 hours after the section of nerve. The changes are:

i. First, the Nissl granules disintegrate into fragments by chromatolysis
ii. Golgi apparatus is disintegrated
iii. Nerve cell body swells due to accumulation of fluid and becomes round
iv. Neurofibrils disappear followed by displacement of the nucleus towards the periphery
v. Sometimes, the nucleus is extruded out of the cell. In this case, death of the neuron occurs and regeneration of the injured nerve is not possible.

Changes in Axon Proximal to Cut End

In the axon, changes occur only up to first node of Ranvier from the site of injury. Degenerative changes that occur in proximal cut end of axon are similar to those changes occurring in distal cut end of the nerve fiber.

■ TRANSNEURONAL DEGENERATION

If an afferent nerve fiber is cut, the degenerative changes occur in the neuron with which the afferent nerve fiber synapses. It is called transneuronal degeneration.

Examples:

i. Chromatolysis in the cells of lateral geniculate body occurs due to sectioning of optic nerve
ii. Degeneration of cells in dorsal horn of spinal cord occurs when the posterior nerve root is cut
iii. Degeneration of cells in ventral horn of spinal cord occurs when there is tumor in cerebral cortex.

■ REGENERATION OF NERVE FIBER

The term regeneration refers to **regrowth** of lost or destroyed part of a tissue. The injured and degenerated nerve fiber can regenerate. It starts as early as 4th day after injury, but becomes more effective only after 30 days and is completed in about 80 days.

■ CRITERIA FOR REGENERATION

Regeneration is possible only if certain criteria are fulfilled by the degenerated nerve fiber:

1. Gap between the cut ends of the nerve should not exceed 3 mm
2. Neurilemma should be present; as neurilemma is absent in CNS, the regeneration of nerve does not occur in CNS
3. Nucleus must be intact; if it is extruded from nerve cell body, the nerve is atrophied and the regeneration does not occur
4. Two cut ends should remain in the same line. Regeneration does not occur if any one end is moved away.

■ STAGES OF REGENERATION

1. First, some pseudopodia like extensions grow from the proximal cut end of the nerve. These extensions are called **fibrils** or **regenerative sprouts.** The number of fibrils is up to 100.
2. Fibrils move towards the distal cut end of the nerve fiber
3. Some of the fibrils enter the **neurilemmal tube** of distal end and form axis cylinder
4. Schwann cells line up in the neurilemmal tube and actually guide the fibrils into the tube. Schwann cells also synthesize nerve growth factors, which attract the fibrils form proximal segment.
5. Axis cylinder is fully established inside the neurilemmal tube. These processes are completed in about 3 months after injury.
6. Myelin sheath is formed by Schwann cells slowly. Myelination is completed in 1 year.
7. Diameter of the nerve fiber gradually increases. However, the degenerated nerve fiber obtains only 80% of original diameter. Newly formed internodes are also shorter than the original ones.
8. In the nerve cell body, first the Nissl granules appear followed by Golgi apparatus
9. Cell looses the excess fluid; nucleus occupies the central portion
10. Though anatomical regeneration occurs in the nerve, functional recovery occurs after a long period.

Neuroglia

Chapter 138

- DEFINITION
- CLASSIFICATION
- CENTRAL NEUROGLIAL CELLS
  - ASTROCYTES
  - MICROGLIA
  - OLIGODENDROCYTES
- PERIPHERAL NEUROGLIAL CELLS
  - SCHWANN CELLS
  - SATELLITE CELLS

DEFINITION

Neuroglia or glia (glia = glue) is the **supporting cell** of the nervous system. Neuroglial cells are **non-excitable** and do not transmit nerve impulse (action potential). So, these cells are also called **non-neural cells** or **glial cells.** When compared to the number of neurons, the number of glial cells is 10 to 15 times greater. Neuroglial cells play an important role in the reaction of nerve during infection. Most commonly, neuroglial cells constitute the site of **tumors** in nervous system.

CLASSIFICATION OF NEUROGLIAL CELLS

Neuroglial cells are distributed in central nervous system (CNS) as well as peripheral nervous system (PNS). Accordingly the neuroglial cells are classified into two types:

A. Central neuroglial cells
B. Peripheral neuroglial cells.

CENTRAL NEUROGLIAL CELLS

Neuroglial cells in CNS are of three types:

1. Astrocytes
2. Microglia
3. Oligodendrocytes.

ASTROCYTES

Astrocytes are star-shaped neuroglial cells present in all the parts of the brain (Fig. 138.1). Two types of astrocytes are found in human brain:

i. Fibrous astrocytes
ii. Protoplasmic astrocytes.

Fibrous Astrocytes

Fibrous astrocytes occupy mainly the white matter. Few fibrous astrocytes are seen in gray matter also. The processes of these cells cover the nerve cells and synapses. This type of astrocytes play an important role in the formation of **blood-brain barrier** by sending processes to the blood vessels of brain, particularly the capillaries, forming tight junction with capillary membrane. **Tight junction** in turn forms the blood-brain barrier.

Protoplasmic Astrocytes

Protoplasmic astrocytes are present mainly in gray matter. The processes of neuroglia run between nerve cell bodies.

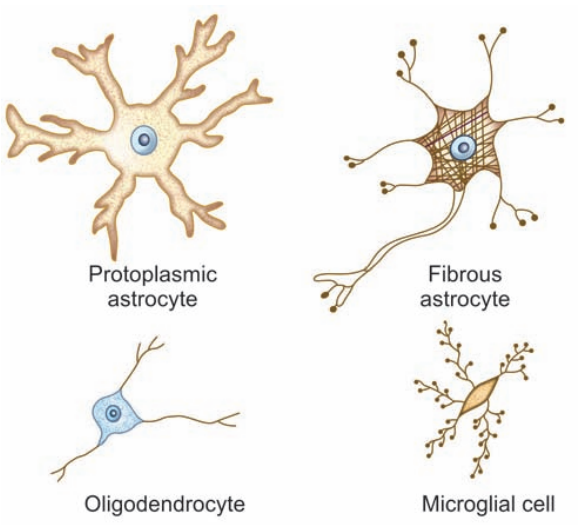

FIGURE 138.1: Neuroglial cells in CNS

Functions of Astrocytes

Astrocytes:

i. Twist around the nerve cells and form the **supporting network** in brain and spinal cord
ii. Form the **blood-brain barrier** and thereby regulate the entry of substances from blood into brain tissues (Chapter 163)
iii. Maintain the **chemical environment** of ECF around CNS neurons
iv. Provide calcium and potassium and regulate neurotransmitter level in synapses
v. Regulate **recycling of neurotransmitter** during synaptic transmission.

■ MICROGLIA

Microglia are the smallest neuroglial cells. These cells are derived from monocytes and enter the tissues of nervous system from blood. These **phagocytic cells** migrate to the site of infection or injury and are often called the **macrophages of CNS.**

Functions of Microglia

Microglia:

i. Engulf and destroy the microorganisms and cellular debris by means of **phagocytosis**
ii. Migrate to the injured or infected area of CNS and act as miniature macrophages.

■ OLIGODENDROCYTES

Oligodendrocytes are the neuroglial cells, which produce myelin sheath around the nerve fibers in CNS. Oligodentrocytes are also called **oligodendroglia.** Oligodendrocytes have only few processes, which are short.

Functions of Oligodendrocytes

Oligodendrocytes:

i. **Provide myelination** around the nerve fibers in CNS where Schwann cells are absent
ii. **Provide support** to the CNS neurons by forming a semi-stiff connective tissue between the neurons.

■ PERIPHERAL NEUROGLIAL CELLS

Neuroglial cells in PNS are of two types:
1. Schwann cells
2. Satellite cells.

■ SCHWANN CELLS

Schwann cells are the major glial cells in PNS (Refer to Chapter 134).

Functions of Schwann Cells

Schwann cells:

i. **Provide myelination** (insulation) around the nerve fibers in PNS
ii. Play important role in **nerve regeneration** (Chapter 137)
iii. Remove cellular debris during regeneration by their phagocytic activity.

■ SATELLITE CELLS

Satellite cells are the glial cells present on the exterior surface of PNS neurons.

Functions of Satellite Cells

Satellite cells:

i. Provide **physical support** to the PNS neurons
ii. Help in regulation of chemical environment of ECF around the PNS neurons.

Receptors

Chapter 139

- DEFINITION
- CLASSIFICATION
  - EXTEROCEPTORS
  - INTEROCEPTORS
- PROPERTIES
  - SPECIFICITY OF RESPONSE
  - ADAPTATION – SENSORY ADAPTATION
  - RESPONSE TO INCREASE IN THE STRENGTH OF STIMULUS
  - SENSORY TRANSDUCTION
  - RECEPTOR POTENTIAL
  - LAW OF PROJECTION

DEFINITION

Receptors are sensory (afferent) nerve endings that terminate in periphery as bare **unmyelinated endings** or in the form of specialized **capsulated structures**. Receptors give response to the stimulus. When stimulated, receptors produce a series of impulses, which are transmitted through the afferent nerves.

Biological Transducers

Actually receptors function like a transducer. Transducer is a device, which converts one form of energy into another. So, receptors are often defined as the biological transducers, which convert (transducer) various forms of **energy** (stimuli) in the environment into **action potentials** in nerve fiber.

CLASSIFICATION OF RECEPTORS

Generally, receptors are classified into two types:

A. Exteroceptors
B. Interoceptors.

EXTEROCEPTORS

Exteroceptors are the receptors, which give response to stimuli arising from **outside the body.**

Exteroceptors are divided into three groups:

1. *Cutaneous Receptors or Mechanoreceptors*

Receptors situated in the skin are called the cutaneous receptors. Cutaneous receptors are also called mechanoreceptors because of their response to **mechanical stimuli** such as touch, pressure and pain. Touch and pressure receptors give response to **vibration** also. Different types of cutaneous receptors are given in Figure 139.1.

2. *Chemoreceptors*

Receptors, which give response to **chemical stimuli,** are called the chemoreceptors.

3. *Telereceptors*

Telereceptors are the receptors that give response to stimuli arising **away from the body.** These receptors are also called the **distance receptors** (Fig. 139.2).

INTEROCEPTORS

Interoceptors are the receptors, which give response to stimuli arising from **within the body.**

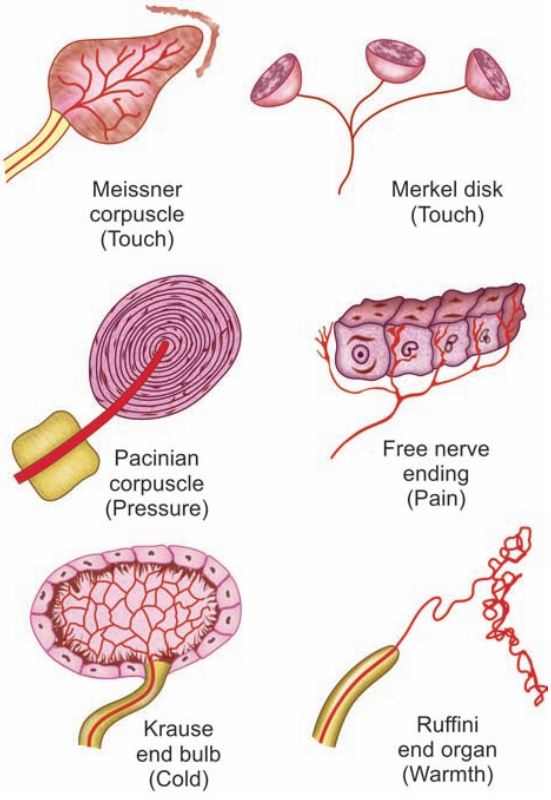

FIGURE 139.1: Cutaneous receptors

Interoceptors are of two types which are as follows:

1. *Viscероceptors*

Receptors situated in the viscera are called visceroceptors. Different visceroceptors are listed in Figure 139.3.

2. *Proprioceptors*

Proprioceptors are the receptors, which give response to **change in the position** of different parts of the body. Proprioceptors are explained in Chapter 156.

■ PROPERTIES OF RECEPTORS

■ 1. SPECIFICITY OF RESPONSE – MÜLLER LAW

Specificity of response or Müller law refers to the response given by a particular type of receptor to a specific sensation. For example, pain receptors give response only to pain sensation. Similarly, temperature receptors give response only to temperature sensation. In addition, each type of sensation depends upon the part of the brain in which its fibers terminate.

Specificity of response is also called **Müller's doctrine** of specific nerve energies.

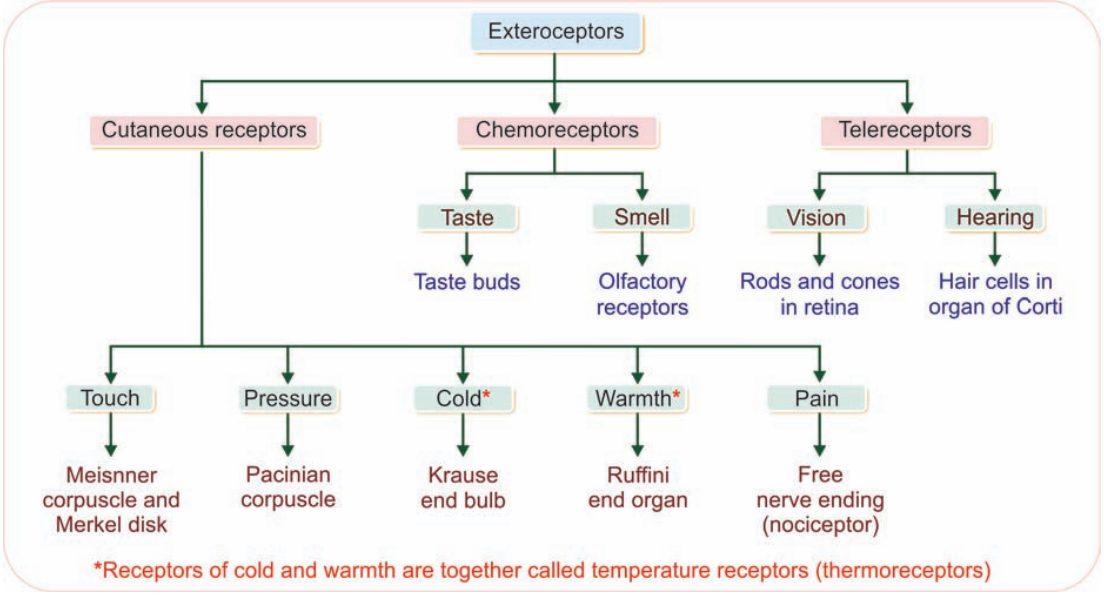

FIGURE 139.2: Exteroceptors

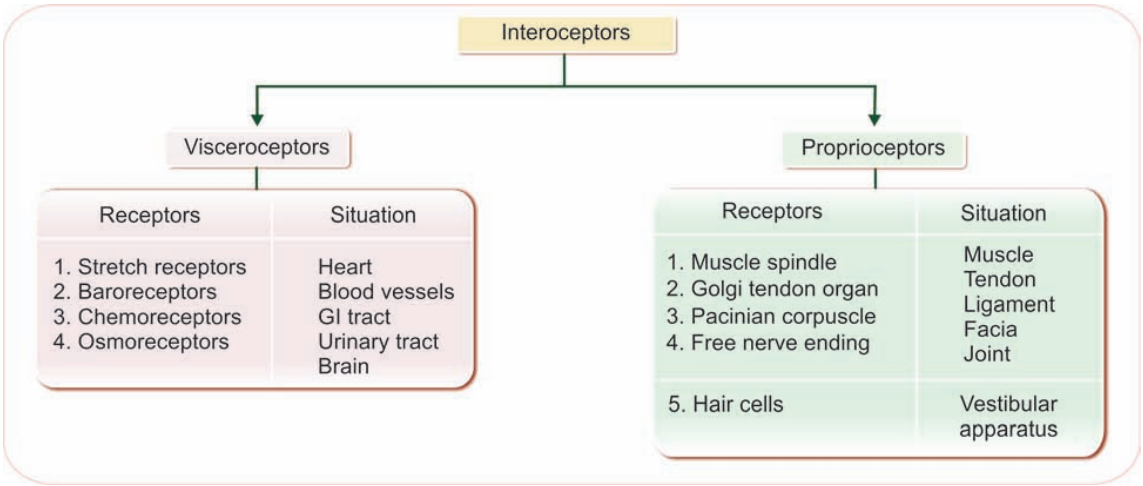

FIGURE 139.3: Interoceptors

■ 2. ADAPTATION – SENSORY ADAPTATION

Adaptation is the decline in discharge of sensory impulses when a receptor is stimulated continuously with constant strength. It is also called sensory adaptation or desensitization.

Depending upon adaptation time, receptors are divided into two types:

i. **Phasic receptors,** which get adapted rapidly. Touch and pressure receptors are the phasic receptors

ii. **Tonic receptors,** which adapt slowly. Muscle spindle, pain receptors and cold receptors are the tonic receptors.

■ 3. RESPONSE TO INCREASE IN STRENGTH OF STIMULUS – WEBER-FECHNER LAW

During the stimulation of a receptor, if the response given by the receptor is to be doubled, the strength of stimulus must be increased 100 times. This phenomenon is called Weber-Fechner law, which states that intensity of response (sensation) of a receptor is directly proportional to logarithmic increase in the intensity of stimulus.

Derivation of Weber-Fechner Law

Weber-Fechner law is derived as follows:

$$R = k \log S$$

Where,

R = Intensity of response (sensation)
k = Constant
S = Intensity of stimulus

■ 4. SENSORY TRANSDUCTION

Sensory transduction in a receptor is a process by which the energy (stimulus) in the environment is converted into electrical impulses (action potentials) in nerve fiber (transduction = conversion of one form of energy into another).

When a receptor is stimulated, it gives response by sending information about the stimulus to CNS. Series of events occur to carry out this function such as the development of receptor potential in the receptor cell and development of action potential in the sensory nerve.

Sensory transduction varies depending upon the type of receptor. For example, the chemoreceptor converts chemical energy into action potential in the sensory nerve fiber. Touch receptor converts mechanical energy into action potential in the sensory nerve fiber.

■ 5. RECEPTOR POTENTIAL

Definition

Receptor potential is a **non-propagated** transmembrane potential difference that develops when a receptor is stimulated. It is also called **generator potential.** Receptor potential is short lived and hence, it is called **transient receptor potential.**

Receptor potential is not action potential. It is a graded potential (Chapter 31). It is similar to excitatory postsynaptic potential (EPSP) in synapse, endplate potential in neuromuscular junction and electrotonic potential in the nerve fiber.

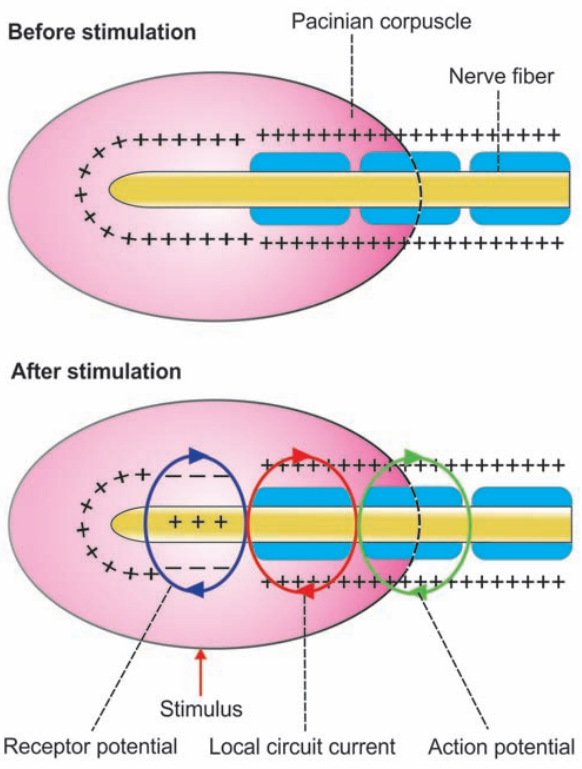

FIGURE 139.4: Receptor potential in pacinian corpuscle. Receptor potential leads to development of local circuit which spreads up to first node within the capsule. It leads to development of action potential in the first node of nerve fiber.

Properties of Receptor Potential

Receptor potential has two important properties.

i. Receptor potential is **non-propagated;** it is confined within the receptor itself
ii. It does not obey **all-or-none law.**

Significance of Receptor Potential

When receptor potential is sufficiently strong (when the magnitude is about 10 mV), it causes development of action potential in the sensory nerve.

Mechanism of Development of Receptor Potential

Pacinian corpuscles are generally used to study the receptor potential because of their large size and anatomical configuration. These corpuscles can be easily dissected from the mesentery of experimental animals. In the pacinian corpuscle, the tip of the nerve fiber is unmyelinated. This unmyelinated nerve tip extends through the corpuscle as **center core fiber.** The concentric layers of the corpuscle surround the core fiber of the nerve.

Pacinian corpuscles give response to pressure stimulus. When pressure stimulus is applied, the Pacinian corpuscle is compressed. This compression causes elongation or change in shape of the corpuscle. The change in shape of the corpuscle leads to the deformation of center core fiber of the corpuscle. This results in the opening of mechanically gated **sodium channels** (Chapter 3). So, the positively charged sodium

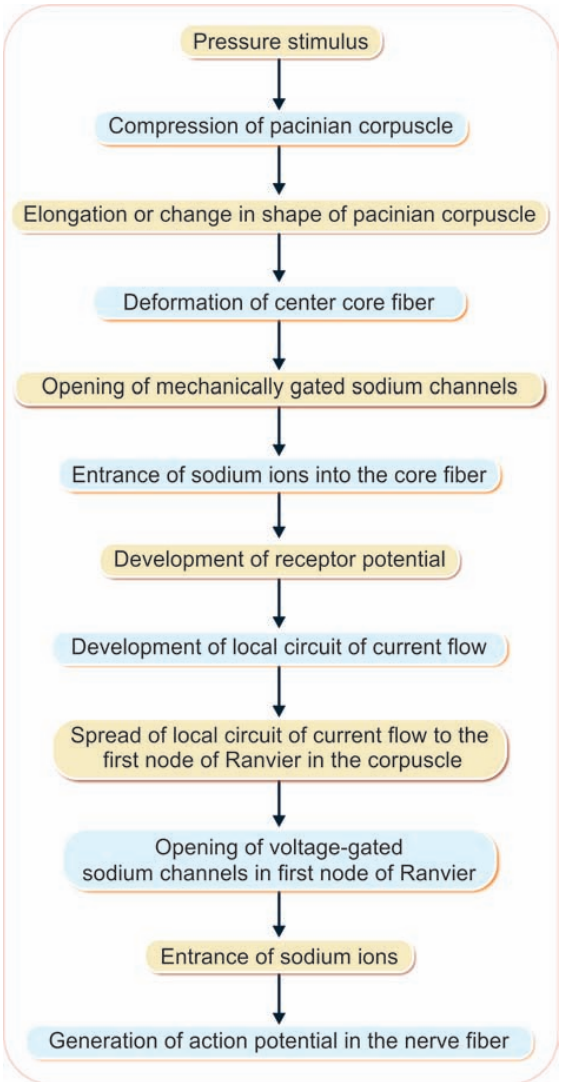
Pressure stimulus
Compression of pacinian corpuscle
Elongation or change in shape of pacinian corpuscle
Deformation of center core fiber
Opening of mechanically gated sodium channels
Entrance of sodium ions into the core fiber
Development of receptor potential
Development of local circuit of current flow
Spread of local circuit of current flow to the first node of Ranvier in the corpuscle
Opening of voltage-gated sodium channels in first node of Ranvier
Entrance of sodium ions
Generation of action potential in the nerve fiber

FIGURE 139.5: Schematic diagram showing development of receptor potential and generation of action potential in nerve fiber.

ions enter the interior of core fiber. This produces a **mild depolarization,** i.e. receptor potential (Fig. 139.4).

Generation of Action Potential in the Nerve Fiber

Receptor potential causes development of a **local circuit** of current flow, which spreads along the unmyelinated part of nerve fiber within the corpuscle.

When this local circuit of current reaches the first node of Ranvier within the corpuscle, it causes opening of voltage-gated sodium channels and entrance of sodium ions into the nerve fiber. This leads to the development of action potential in the nerve fiber (Fig. 139.5).

■ 6. LAW OF PROJECTION

When a sensory pathway from receptor to cerebral cortex is stimulated on any particular site along its course, the sensation caused by stimulus is always felt (referred) at the location of receptor, irrespective of site stimulated. This phenomenon is known as law of projection.

Examples of Law of Projection

i. If somesthetic area in right cerebral cortex, which receives sensation from left hand is stimulated, sensations are felt in left hand and not in head.
ii. Sensation complained by amputated patients in the missing limb **(phantom limb)** is the best example of law of projection. For example, if a leg has been amputated, the cut end heals with scar formation. The cut ends of nerve fibers are merged within the scar. If the cut end of sensory fibers are stimulated during movement of thigh, the patient feels as if the sensation is originating from **non-existent leg.** Sometimes, the patient feels pain in non-existent limb. This type of pain is called **phantom limb pain.**

Synapse

Chapter 140

- DEFINITION
- CLASSIFICATION
  - ANATOMICAL CLASSIFICATION
  - FUNCTIONAL CLASSIFICATION
- FUNCTIONAL ANATOMY
- FUNCTIONS
  - EXCITATORY FUNCTION
  - INHIBITORY FUNCTION
- PROPERTIES
  - ONE WAY CONDUCTION – BELL-MAGENDIE LAW
  - SYNAPTIC DELAY
  - FATIGUE
  - SUMMATION
  - ELECTRICAL PROPERTY
- CONVERGENCE AND DIVERGENCE
  - CONVERGENCE
  - DIVERGENCE

DEFINITION

Synapse is the junction between two neurons. It is not an anatomical continuation. But, it is only a physiological continuity between two nerve cells.

CLASSIFICATION OF SYNAPSE

Synapse is classified by two methods:

A. Anatomical classification
B. Functional classification.

ANATOMICAL CLASSIFICATION

Usually synapse is formed by axon of one neuron ending on the cell body, dendrite or axon of the next neuron. Depending upon **ending of axon,** synapse is classified into three types:

1. **Axoaxonic synapse** in which axon of one neuron terminates on axon of another neuron
2. **Axodendritic synapse** in which the axon of one neuron terminates on dendrite of another neuron
3. **Axosomatic synapse** in which axon of one neuron ends on soma (cell body) of another neuron (Fig. 140.1).

FUNCTIONAL CLASSIFICATION

Functional classification of synapse is on the basis of **mode of impulse transmission.** According to this, synapse is classified into two categories:

1. Electrical synapse
2. Chemical synapse.

However, generally the word synapse refers to a chemical synapse.

1. *Electrical Synapse*

Electrical synapse is the synapse in which the physiological continuity between the presynaptic and the post-

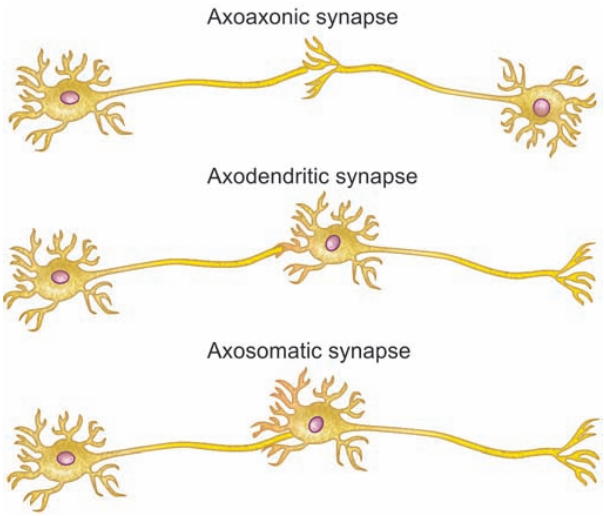

FIGURE 140.1: Anatomical synapses

synaptic neurons is provided by **gap junction** between the two neurons (Fig. 140.2). There is **direct exchange** of ions between the two neurons through the gap junction. Because of this reason, the action potential reaching the terminal portion of presynaptic neuron directly enters the postsynaptic neuron.

Important feature of electrical synapse is that the synaptic delay is very less because of the direct flow of current. Moreover, the impulse is transmitted in either direction through the electrical synapse.

This type of impulse transmission occurs in some tissues like the cardiac muscle fibers, smooth muscle fibers of intestine and the epithelial cells of lens in the eye.

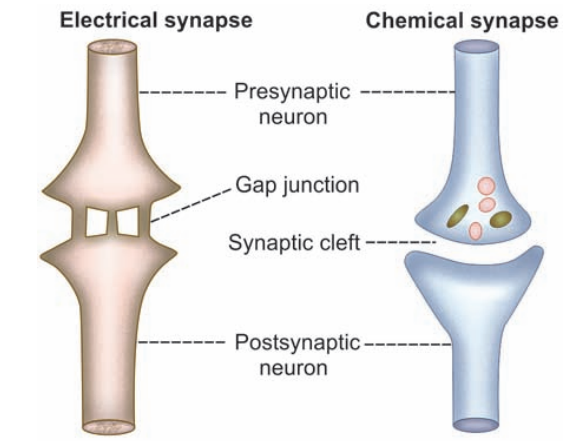

FIGURE 140.2: Electrical and chemical synapse

2. Chemical Synapse

Chemical synapse is the junction between a nerve fiber and a muscle fiber or between two nerve fibers, through which the signals are transmitted by the release of chemical transmitter. In the chemical synapse, there is no continuity between the two neurons because of the presence of a space called **synaptic cleft** between the two neurons. Action potential reaching the presynaptic terminal causes release of neurotransmitter substance from the vesicles of this terminal. Neurotransmitter reaches the postsynaptic neuron through synaptic cleft and causes the production of potential change. Structure and functions of the chemical synapse are given here.

■ FUNCTIONAL ANATOMY OF CHEMICAL SYNAPSE

Functional anatomy of a chemical synapse is shown in Figure 140.3. Neuron from which the axon arises is called the **presynaptic neuron** and the neuron on which the axon ends is called **postsynaptic neuron.** Axon of the presynaptic neuron divides into many small branches before forming the synapse. These branches are known as presynaptic **axon terminals.**

Types of Axon Terminals

1. *Terminal knobs*

Some of the terminals are enlarged slightly like knobs called **terminal knobs.** Terminal knobs are concerned with excitatory function of the synapse.

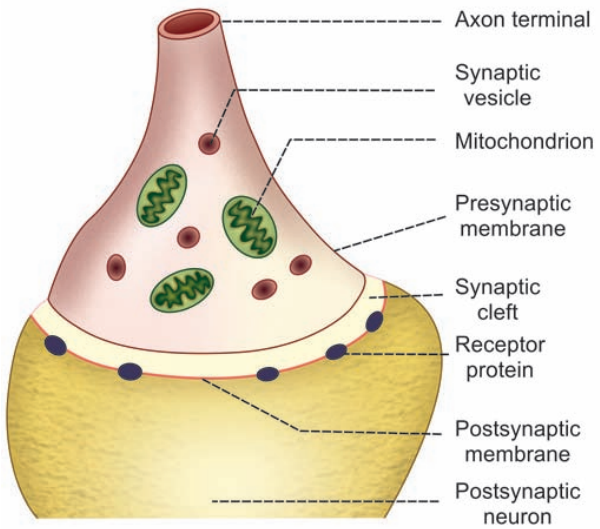

FIGURE 140.3: Structure of chemical synapse

2. *Terminal coils or free endings*

Other terminals are wavy or coiled with free ending without the knob. These terminals are concerned with inhibitory function.

Structures of Axon Terminals and Presynaptic Membrane

Presynaptic axon terminal has a definite intact membrane known as **presynaptic membrane.**

Axon terminal has two important structures:

i. **Mitochondria,** which help in the synthesis of neurotransmitter substance
ii. **Synaptic vesicles,** which store neurotransmitter substance.

Synaptic Cleft and Postsynaptic Membrane

Membrane of the postsynaptic neuron is called **postsynaptic membrane.** It contains some **receptor proteins.** Small space in between the presynaptic membrane and the postsynaptic membrane is called **synaptic cleft.** The **basal lamina** of this cleft contains **cholinesterase,** which destroys **acetylcholine.**

■ FUNCTIONS OF SYNAPSE

Main function of the synapse is to transmit the impulses, i.e. action potential from one neuron to another. However, some of the synapses inhibit these impulses. So the impulses are not transmitted to the postsynaptic neuron.

On the basis of functions, synapses are divided into two types:

1. Excitatory synapses, which transmit the impulses (excitatory function)
2. Inhibitory synapses, which inhibit the transmission of impulses (inhibitory function).

■ EXCITATORY FUNCTION

Excitatory Postsynaptic Potential

Excitatory postsynaptic potential (EPSP) is the non-propagated electrical potential that develops during the process of synaptic transmission. When the action potential reaches the presynaptic axon terminal, the voltage-gated **calcium channels** at the presynaptic membrane are opened. Now, the **calcium ions** enter the axon terminal from ECF (Fig. 140.4).

Calcium ions cause the release of neurotransmitter substance from the vesicles by means of **exocytosis.**

Neurotransmitter, which is excitatory in function (excitatory neurotransmitter) passes through presynaptic membrane and synaptic cleft and reaches the postsynaptic membrane. Now, the neurotransmitter binds with receptor protein present in postsynaptic membrane to form neurotransmitter-receptor complex. Neurotransmitter-receptor complex causes production of a non-propagated EPSP. Common excitatory neurotransmitter in a synapse is **acetylcholine.**

Mechanism of Development of EPSP

Neurotransmitter-receptor complex causes opening of ligand-gated **sodium channels.** Now, the **sodium ions**

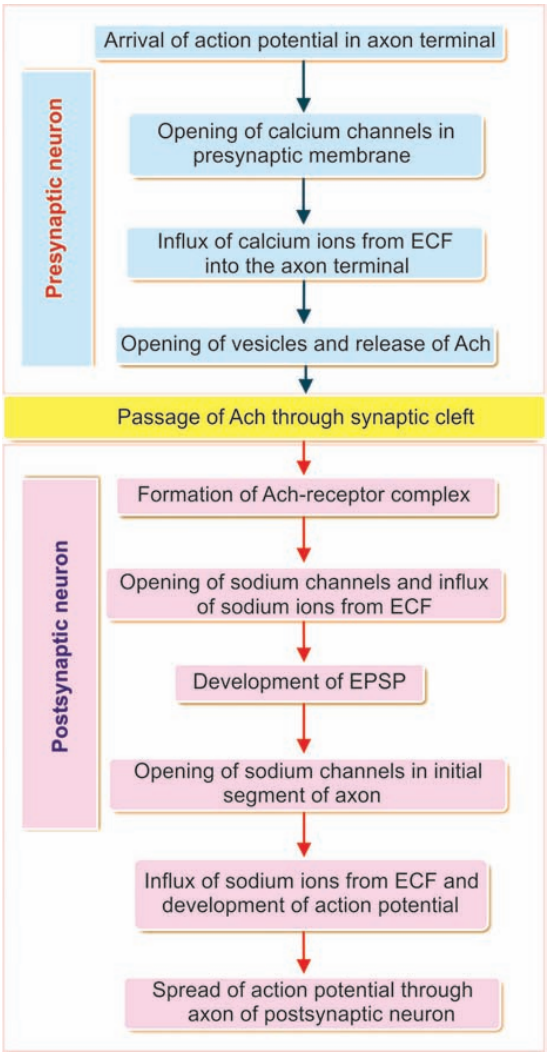
Arrival of action potential in axon terminal
Presynaptic neuron
Opening of calcium channels in presynaptic membrane
Influx of calcium ions from ECF into the axon terminal
Opening of vesicles and release of Ach
Passage of Ach through synaptic cleft
Postsynaptic neuron
Formation of Ach-receptor complex
Opening of sodium channels and influx of sodium ions from ECF
Development of EPSP
Opening of sodium channels in initial segment of axon
Influx of sodium ions from ECF and development of action potential
Spread of action potential through axon of postsynaptic neuron

FIGURE 140.4: Sequence of events during synaptic transmission. Ach = Acetylcholine, ECF = Extracellular fluid, EPSP = Excitatory postsynaptic potential.

from ECF enter the cell body of postsynaptic neuron. As the sodium ions are positively charged, resting membrane potential inside the cell body is altered and **mild depolarization** develops. This type of mild depolarization is called EPSP. It is a **local potential** (response) in the synapse.

Properties of EPSP

EPSP is confined only to the synapse. It is a **graded potential** (Chapter 31). It is similar to receptor potential and endplate potential.

EPSP has two properties:

1. It is non-propagated
2. It does not obey all-or-none law.

Significance of EPSP

EPSP is not transmitted into the axon of postsynaptic neuron. However, it causes development of action potential in the axon.

When EPSP is strong enough, it causes the opening of voltage-gated **sodium channels** in the initial segment of axon. Now, due to the entrance of **sodium ions,** the depolarization occurs in the initial segment of axon and thus, the action potential develops. From here, the action potential spreads to other segment of the axon.

■ INHIBITORY FUNCTION

Inhibition of synaptic transmission is classified into five types:

1. Postsynaptic or direct inhibition
2. Presynaptic or indirect inhibition
3. Negative feedback or Renshaw cell inhibition
4. Feedforward inhibition
5. Reciprocal inhibition.

1. *Postsynaptic or Direct Inhibition*

Postsynaptic inhibition is the type of synaptic inhibition that occurs due to the release of an inhibitory neurotransmitter from presynaptic terminal instead of an excitatory neurotransmitter substance. It is also called **direct inhibition.** Inhibitory neurotransmitters are gamma-aminobutyric acid **(GABA),** dopamine and glycine.

Action of GABA – development of inhibitory postsynaptic potential

Inhibitory postsynaptic potential (IPSP) is the electrical potential in the form of **hyperpolarization** that develops during postsynaptic inhibition. Inhibitory neurotransmitter substance acts on postsynaptic membrane by binding with receptor. Transmitter-receptor complex opens the ligand-gated **potassium channels** instead of sodium channels. Now, the **potassium ions,** which are available in plenty in the cell body of postsynaptic neuron move to ECF. Simultaneously, **chloride channels** also open and chloride ions (which are more in ECF) move inside the cell body of postsynaptic neuron. The exit of potassium ions and influx of chloride ions cause **more negativity** inside, leading to **hyperpolarization.** Hyperpolarized state of the synapse inhibits synaptic transmission (Fig. 140.5).

2. *Presynaptic or Indirect Inhibition*

Presynaptic inhibition occurs due to the failure of presynaptic axon terminal to release sufficient quantity of excitatory neurotransmitter substance. It is also called indirect inhibition.

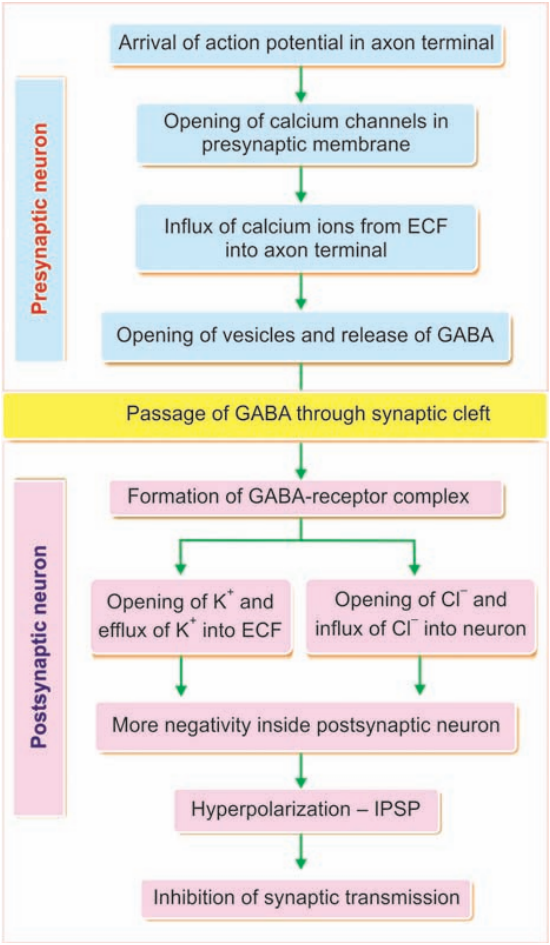
Presynaptic neuron
Arrival of action potential in axon terminal
Opening of calcium channels in presynaptic membrane
Influx of calcium ions from ECF into axon terminal
Opening of vesicles and release of GABA
Passage of GABA through synaptic cleft
Postsynaptic neuron
Formation of GABA-receptor complex
Opening of K+ and efflux of K+ into ECF
Opening of Cl− and influx of Cl− into neuron
More negativity inside postsynaptic neuron
Hyperpolarization – IPSP
Inhibition of synaptic transmission

FIGURE 140.5: Sequence of events during postsynaptic inhibition. GABA = Gamma-aminobutyric acid, ECF = Extracellular fluid, IPSP = Inhibitory postsynaptic potential.

Presynaptic inhibition is mediated by axoaxonal synapses. It is prominent in **spinal cord** and regulates the propagation of information to higher centers in brain.

Normally, during synaptic transmission, action potential reaching the presynaptic neuron produces development of EPSP in the postsynaptic neuron. But, in spinal cord, a **modulatory neuron** called **presynaptic inhibitory neuron** forms an axoaxonic synapse with the presynaptic neuron (Fig. 140.6).

This inhibitory neuron inhibits the presynaptic neuron and decreases the magnitude of action potential in presynaptic neuron. The **smaller action potential** reduces **calcium influx.** This in turn decreases the quantity of neurotransmitter released by presynaptic neuron. So the magnitude of EPSP in postsynaptic neuron is decreased resulting in synaptic inhibition.

3. *Renshaw Cell or Negative Feedback Inhibition*

Negative feedback inhibition is the type of synaptic inhibition, which is caused by Renshaw cells in **spinal cord.** Renshaw cells are small motor neurons present in anterior gray horn of spinal cord (Chapter 143). Anterior nerve root consists of nerve fibers, which leave the spinal cord. These nerve fibers arise from α-motor neurons in anterior gray horn of the spinal cord and reach the effector organ, muscles. Some of the fibers called collaterals fibers terminate on Renshaw cells instead of leaving the spinal cord.

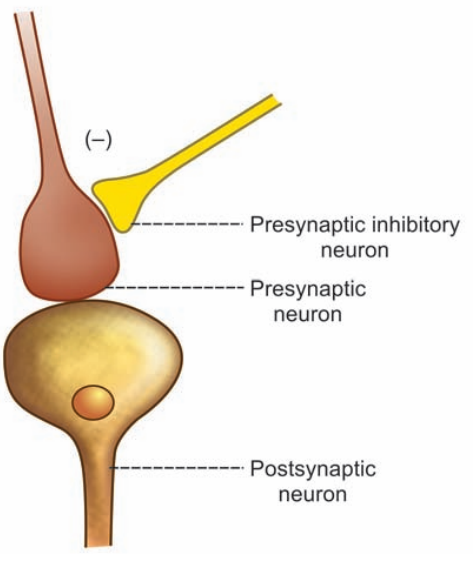

FIGURE 140.6: Presynaptic inhibition

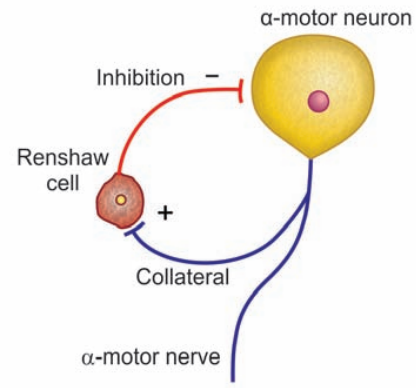

FIGURE 140.7: Renshaw cell inhibition

When motor neurons send motor impulses, some of the impulses reach the Renshaw cell by passing through **collaterals.** Now, the Renshaw cell is stimulated. In turn, it sends inhibitory impulses to α-motor neurons so that, the discharge from motor neurons is reduced (Fig. 140.7).

In this way, Renshaw cell inhibition represents a **negative feedback mechanism.** A Renshaw cell may be supplied by more than one alpha motor neuron collateral and it may synapse on many motor neurons.

4. *Feedforward Inhibition*

Feedforward synaptic inhibition occurs in **cerebellum** and it controls the **neuronal activity** in cerebellum.

During the process of neuronal activity in cerebellum, stellate cells and basket cells, which are activated by granule cells, inhibit the **Purkinje cells** by releasing **GABA** (Chapter 150). This type of inhibition is called feedforward inhibition.

5. *Reciprocal Inhibition*

Inhibition of antagonistic muscles when a group of muscles are activated is called reciprocal inhibition. It is because of **reciprocal innervation** (Chapter 142).

Significance of Synaptic Inhibition

Synaptic inhibition in CNS limits the number of impulses going to muscles and enables the muscles to act properly and appropriately. Thus, the inhibition helps to select exact number of impulses and to omit or block the excess ones. When a poison like **strychnine** is introduced into the body, it destroys the inhibitory

function at synaptic level resulting in continuous and convulsive contraction even with slight stimulation. In the nervous disorders like **parkinsonism,** the inhibitory system is impaired resulting in rigidity.

■ PROPERTIES OF SYNAPSE

■ 1. ONE WAY CONDUCTION – BELL-MAGENDIE LAW

According to Bell-Magendie law, the impulses are transmitted only in **one direction** in synapse, i.e. from presynaptic neuron to postsynaptic neuron.

■ 2. SYNAPTIC DELAY

Synaptic delay is a short delay that occurs during the transmission of impulses through the synapse. It is due to the time taken for:

i. Release of neurotransmitter
ii. Passage of neurotransmitter from axon terminal to postsynaptic membrane
iii. Action of the neurotransmitter to open the ionic channels in postsynaptic membrane.

Normal duration of synaptic delay is 0.3 to 0.5 millisecond. Synaptic delay is one of the causes for **reaction time** of reflex activity.

Significance of Determining Synaptic Delay

Determination of synaptic delay helps to find out whether the pathway for a reflex is monosynapatic or polysynaptic.

■ 3. FATIGUE

During continuous muscular activity, synapse becomes the seat of fatigue along with **Betz cells** present in motor area of frontal lobe of cerebral cortex (Refer Chapter 30 for details of fatigue). Fatigue at synapse is due to the **depletion of neurotransmitter** substance, acetylcholine.

Depletion of acetylcholine occurs because of two factors:

i. Soon after the action, acetylcholine is destroyed by acetylcholinesterase
ii. Due to continuous action, new acetylcholine is not synthesized.

■ 4. SUMMATION

Summation is the fusion of effects or progressive increase in the excitatory postsynaptic potential in postsynaptic neuron when many presynaptic excitatory terminals are stimulated simultaneously or when single presynaptic terminal is stimulated repeatedly. Increased EPSP triggers the axon potential in the initial segment of axon of postsynaptic neuron (Fig.140.8).

Summation is of two types:

i. *Spatial Summation*

Spatial summation occurs when many presynaptic terminals are stimulated simultaneously.

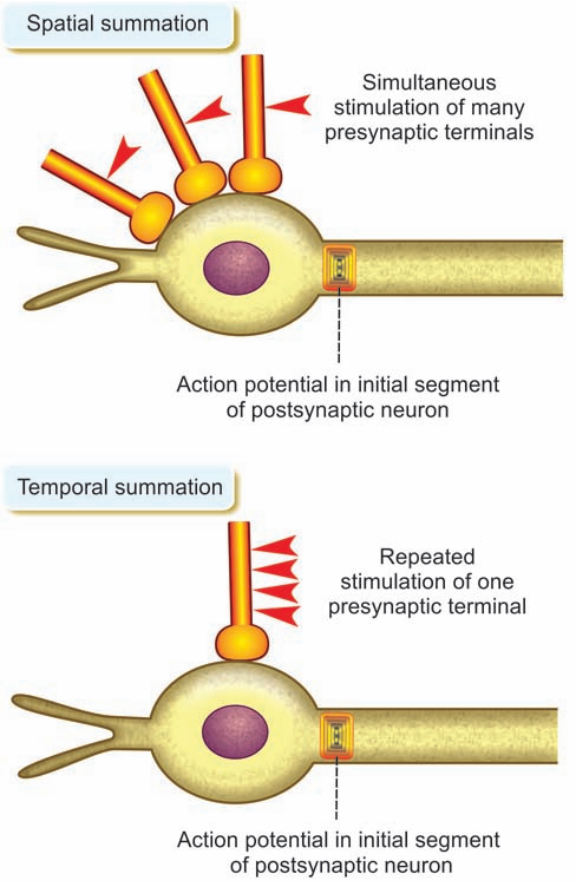
Spatial summation
Simultaneous stimulation of many presynaptic terminals
Action potential in initial segment of postsynaptic neuron
Temporal summation
Repeated stimulation of one presynaptic terminal
Action potential in initial segment of postsynaptic neuron

FIGURE 140.8: Spatial and temporal summation

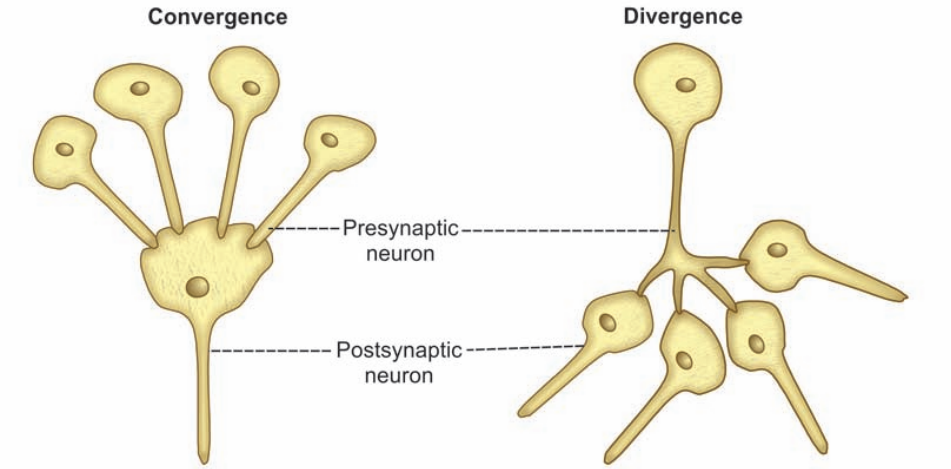

FIGURE 140.9: Convergence and divergence

ii. *Temporal Summation*

Temporal summation occurs when one presynaptic terminal is stimulated repeatedly.

Thus, both spatial summation and temporal summation play an important role in facilitation of response.

■ 5. ELECTRICAL PROPERTY

Electrical properties of the synapse are the EPSP and IPSP, which are already described in this chapter.

■ CONVERGENCE AND DIVERGENCE

■ CONVERGENCE

Convergence is the process by which many presynaptic neurons terminate on a single postsynaptic neuron (Fig.140.9).

■ DIVERGENCE

Divergence is the process by which one presynaptic neuron terminates on many postsynaptic neurons.

Neurotransmitters

Chapter 141

- DEFINITION
- HISTORY
- CRITERIA
- CLASSIFICATION
- TRANSPORT AND RELEASE
- INACTIVATION
- REUPTAKE
- IMPORTANT NEUROTRANSMITTERS
- NEUROMODULATORS
- COTRANSMISSION AND COTRANSMITTERS

DEFINITION

Neurotransmitter is a chemical substance that acts as a **mediator** for the transmission of nerve impulse from one neuron to another neuron through a synapse.

HISTORY

Existence of neurotransmitter was first discovered by an Austrian scientist named **Otto Loewi** in 1921. He dreamt of an experiment, which he did practically and came out with this discovery.

Loewi Experiment

Otto Loewi used two frogs for this experiment. Heart of frog A was with intact vagus nerve and was placed in a saline-filled chamber. Heart of frog B was denervated and was kept in another saline-filled chamber. Both the chambers were connected in such a way that the fluid from chamber of frog A could flow into the chamber of frog B.

When vagus nerve of frog A was electrically stimulated, slowing of heart rate was observed. After a short delay, the heart rate in frog B also was found to be slowing down. From this observation, Loewi speculated that some chemical substance must have been released from the vagus nerve of frog A, which was responsible for the slowing down of the heart rate in frog B. He named it as **'vagusstoff'.** Later this chemical substance was considered as a neurotransmitter and called acetylcholine (Ach).

CRITERIA FOR NEUROTRANSMITTER

Nowadays, many substances are categorized as neurotransmitters. To consider a substance as a neurotransmitter, it should fulfill certain criteria as given below:

1. It must be found in a neuron
2. It must be produced by a neuron
3. It must be released by a neuron
4. After release, it must act on a target area and produce some biological effect
5. After the action, it must be inactivated.

CLASSIFICATION OF NEUROTRANSMITTERS

DEPENDING UPON CHEMICAL NATURE

Many substances of different chemical nature are identified as neurotransmitters. Depending upon their

chemical nature, neurotransmitters are classified into three groups.

1. *Amino Acids*

Neurotransmitters of this group are involved in **fast synaptic transmission** and are inhibitory and excitatory in action. GABA, glycine, glutamate (glutamic acid) and aspartate (aspartic acid) belong to this group.

2. *Amines*

Amines are the modified amino acids. These neurotransmitters involve in **slow synaptic transmission.** These neurotransmitters are also inhibitory and excitatory in action. Noradrenaline, adrenaline, dopamine, serotonin and histamine belong to this group.

3. *Others*

Some neurotransmitters do not fit into any of these categories. One such substance is acetylcholine. It is formed from the choline and acetyl coenzyme A in the presence of the enzyme called choline acetyltransferase. Another substance included in this category is the soluble gas nitric oxide (NO).

■ DEPENDING UPON FUNCTION

Some of the neurotransmitters cause excitation of postsynaptic neuron while others cause inhibition.

Thus, neurotransmitters are classified into two types:

1. Excitatory neurotransmitters
2. Inhibitory neurotransmitters.

1. *Excitatory Neurotransmitters*

Excitatory neurotransmitter is a chemical substance, which is responsible for the conduction of impulse from presynaptic neuron to postsynaptic neuron. Neurotransmitter released from the presynaptic axon terminal does not cause development of action potential in the postsynaptic neuron. Rather, it causes some change in the resting membrane potential, i.e. slight depolarization by the opening of sodium channels in the postsynaptic membrane and the influx of sodium ions from ECF. This slight depolarization is called **excitatory postsynaptic potential (EPSP).** EPSP in turn causes development of action potential in the initial segment of the axon of the postsynaptic neuron (Chapter 140).

TABLE 141.1: Neurotransmitters

Group	Name	Site of secretion	Action
Aminoacids	GABA	Cerebral cortex, cerebellum, basal ganglia, retina and spinal cord	Inhibitory
	Glycine	Forebrain, brainstem, spinal cord and retina	Inhibitory
	Glutamate	Cerebral cortex, brainstem and cerebellum	Excitatory
	Aspartate	Cerebellum, spinal cord and retina	Excitatory
Amines	Noradrenaline	Postganglionic adrenergic sympathetic nerve endings, cerebral cortex, hypothalamus, basal ganglia, brainstem, locus coeruleus and spinal cord	Excitatory and inhibitory
	Adrenaline	Hypothalamus, thalamus and spinal cord	Excitatory and inhibitory
	Dopamine	Basal ganglia, hypothalamus, limbic system, neocortex, retina and sympathetic ganglia	Inhibitory
	Serotonin	Hypothalamus, limbic system, cerebellum, spinal cord, retina, gastrointestinal (GI) tract, lungs and platelets	Inhibitory
	Histamine	Hypothalamus, cerebral cortex, GI tract and mast cells	Excitatory
Others	Nitric oxide	Many parts of CNS, neuromuscular junction and GI tract	Excitatory
	Acetylcholine	Preganglionic parasympathetic nerve endings Postganglionic parasympathetic nerve endings Preganglionic sympathetic nerve endings Postganglionic sympathetic cholinergic nerve endings Neuromuscular junction, cerebral cortex, hypothalamus, basal ganglia, thalamus, hippocampus and amacrine cells of retina	Excitatory

GABA = Gamma-aminobutyric acid, CNS = Central nervous system.

Common excitatory neurotransmitters are **acetylcholine** and **noradrenaline.**

2. *Inhibitory Neurotransmitters*

Inhibitory neurotransmitter is a chemical substance, which inhibits the conduction of impulse from the presynaptic neuron to the postsynaptic neuron (Chapter 140). When it is released from the presynaptic axon terminal due to the arrival of action potential, it causes opening of potassium channels in the postsynaptic membrane and efflux of potassium ions. This leads to hyperpolarization, which is called the **inhibitory postsynaptic potential (IPSP).** When IPSP is developed, the action potential is not generated in the postsynaptic neuron.

Common inhibitory neurotransmitters are **gamma-aminobutyric acid (GABA)** and dopamine.

■ TRANSPORT AND RELEASE OF NEUROTRANSMITTER

Neurotransmitter is produced in the cell body of the neuron and is transported through axon. At the axon terminal, the neurotransmitter is stored in small packets called vesicles. Under the influence of a stimulus, these vesicles open and release the neurotransmitter into synaptic cleft. It binds to specific receptors on the surface of the postsynaptic cell. Receptors are G proteins, protein kinase or ligand-gated receptors.

■ INACTIVATION OF NEUROTRANSMITTER

After the execution of the action, neurotransmitter is inactivated by four different mechanisms:

1. It diffuses out of synaptic cleft to the area where it has no action
2. It is destroyed or disintegrated by specific enzymes
3. It is engulfed and removed by astrocytes (macrophages)
4. It is removed by means of reuptake into the axon terminal.

■ REUPTAKE OF NEUROTRANSMITTER

Reuptake is a process by which the neurotransmitter is taken back from synaptic cleft into the axon terminal after execution of its action. Reuptake process involves a specific carrier protein for each neurotransmitter.

■ IMPORTANT NEUROTRANSMITTERS

Some of the important neurotransmitters are described here. Details of neurotransmitters are given in Tables 141.1 and 141.2.

■ ACETYLCHOLINE

Acetylcholine is a **cholinergic neurotransmitter.** It possesses excitatory function. It produces the excitatory function by opening the ligand-gated sodium channels (Chapters 32 and 140).

Source

Acetylcholine is the transmitter substance at the neuromuscular junction and synapse. It is also released by the following nerve endings:

1. Preganglionic parasympathetic nerve
2. Postganglionic parasympathetic nerve
3. Preganglionic sympathetic nerve
4. Postganglionic sympathetic cholinergic nerves:
   i. Nerves supplying eccrine sweat glands
   ii. Sympathetic vasodilator nerves in skeletal muscle
5. Nerves in amacrine cells of retina
6. Many regions of brain.

Synthesis

Ach is synthesized in the cholinergic nerve endings. Synthesis takes place in axoplasm and Ach is stored in the vesicles. It is synthesized from acetyl coenzyme A (acetyl CoA). It combines with choline in the presence of the enzyme choline acetyltransferase to form Ach.

TABLE 141.2: Excitatory and inhibitory neurotransmitters

Excitatory neurotransmitters	Inhibitory neurotransmitters	Neurotransmitters with excitatory and inhibitory actions
1. Acetylcholine 2. Nitric oxide 3. Histamine 4. Glutamate 5. Aspartate	1. Gamma-aminobutyric acid 2. Glycine 3. Dopamine 4. Serotonin	1. Noradrenaline 2. Adrenaline

Fate

Action of Ach is short lived. Within one millisecond after the release from the vesicles, it is hydrolyzed into acetate and choline by the enzyme **acetylcholinesterase** (Fig. 141.1). This enzyme is present in basal lamina of the synaptic cleft.

Acetylcholine Receptors

There are two types of receptors through which Ach acts on the tissues namely, **muscarinic receptors** and **nicotinic receptors.** Reason for the terminology of these receptors is as follows: Poisonous substance from toadstools called **muscarine,** acts on a specific group of receptors known as muscarinic receptors; similarly, another substance called **nicotine** acts on a specific group of receptors known as nicotinic receptors but Ach acts on both the receptors.

Muscarinic receptors are present in all the organs innervated by the postganglionic fibers of the parasympathetic system and by the sympathetic cholinergic nerves. Nicotinic receptors are present in the synapses between preganglionic and postganglionic neurons of both sympathetic and parasympathetic systems.

Nicotinic receptors are also present in the neuromuscular junction on membrane of skeletal muscle.

■ NORADRENALINE

Noradrenaline is the neurotransmitter in adrenergic nerve fibers. It is released from the following structures:

1. Postganglionic sympathetic nerve endings
2. Cerebral cortex

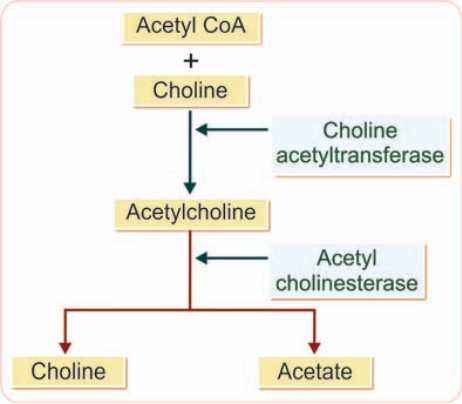

FIGURE 141.1: Synthesis and breakdown of acetylcholine

3. Hypothalamus
4. Basal ganglia
5. Brainstem
6. Locus ceruleus in pons
7. Spinal cord.

In many places, noradrenaline is the **excitatory** chemical mediator and in very few places, it causes **inhibition.** It is believed to be involved in dreams, arousal and elevation of moods. Refer Chapter 71 for the synthesis of noradrenaline.

■ DOPAMINE

Dopamine is secreted by nerve endings in the following areas:

1. Basal ganglia
2. Hypothalamus
3. Limbic system
4. Neocortex
5. Retina
6. Small, intensely fluorescent cells in sympathetic ganglia.

Dopamine possesses **inhibitory** action. Prolactin inhibitory hormone secreted by hypothalamus is considered to be dopamine. Refer Chapter 71 for the synthesis of dopamine.

■ SEROTONIN

Serotonin is otherwise known as **5-hydroxytryptamine** (5-HT). It is synthesized from tryptophan by hydroxylation and decarboxylation. Large amount of serotonin (90%) is found in enterochromatin cells of GI tract. Small amount is found in platelets and nervous system. It is secreted in the following structures:

1. Hypothalamus
2. Limbic system
3. Cerebellum
4. Dorsal raphe nucleus of midbrain
5. Spinal cord
6. Retina
7. GI tract
8. Lungs
9. Platelets.

It is an **inhibitory** substance. It inhibits impulses of pain sensation in posterior gray horn of spinal cord. It is supposed to cause depression of mood and sleep (Chapter 145). Serotonin causes vasoconstriction, platelet aggregation and smooth muscle contraction. It also controls food intake.

HISTAMINE

Histamine is secreted in nerve endings of hypothalamus, limbic cortex and other parts of cerebral cortex. It is also secreted by gastric mucosa and mast cells. Histamine is an **excitatory** neurotransmitter. It is believed to play an important role in arousal mechanism.

GAMMA-AMINOBUTYRIC ACID

Gamma-aminobutyric acid (GABA) is an **inhibitory** neurotransmitter in synapses particularly in CNS. It is responsible for presynaptic inhibition. It is secreted by nerve endings in the following structures:

1. Cerebral cortex
2. Cerebellum
3. Basal ganglia
4. Spinal cord
5. Retina.

GABA causes synaptic inhibition by opening potassium channels and chloride channels. So, potassium comes out of synapse and chloride enters in (Chapter 140). This leads to hyperpolarization, which is known as inhibitory postsynaptic potential (IPSP).

SUBSTANCE P

Substance P is a neuropeptide that acts as a neurotransmitter and as a neuromodulator (see below). Substance P is a polypeptide with 11 amino acid residues. It belongs to a family of 3 related peptides called **neurokinins** or **tachykinins.** The other peptides of this family are neurokinin A and neurokinin B which are not well known like substance P.

Substance P is secreted by the nerve endings (first order neurons) of pain pathway in spinal cord. It is also found in many peripheral nerves, different parts of brain particularly hypothalamus, retina and intestine (Chapter 44).

It mediates **pain sensation.** It is a potent vasodilator in CNS. It is responsible for regulation of anxiety, stress, mood disorders, neurotoxicity, nausea and vomiting.

NITRIC OXIDE

Nitric oxide (NO) is a neurotransmitter in the CNS. It is also the important neurotransmitter in the neuromuscular junctions between the inhibitory motor fibers of intrinsic nerve plexus and the smooth muscle fibers of GI tract.

Nitric oxide acts as a mediator for the **dilator effect** of Ach on small arteries. In the smooth muscle fibers of arterioles, NO activates the enzyme guanylyl cyclase, which in turn causes formation of cyclic guanosine monophosphate (cGMP) from GMP. The cGMP is a smooth muscle relaxant and it causes dilatation of arterioles. Thus, NO indirectly causes dilatation of arterioles.

Peculiarity of NO is that it is neither produced by the neuronal cells nor stored in the vesicles. It is produced by **non-neuronal cells** like the endothelial cells of blood vessels. From the site of production, it diffuses into the neuronal and non-neuronal cells where it exerts its action.

NEUROMODULATORS

Definition

Neuromodulator is the chemical messenger, which modifies and regulates activities that take place during the synaptic transmission.

These peptides do not propagate nerve impulses like neurotransmitters.

Neuromodulators Vs Neurotransmitters

Neuromodulators are distinct from neurotransmitters. However, both the terms are wrongly interchanged. Neurotransmitters propagate nerve impulses through synapse whereas neuromodulators modify and regulate the activities of synaptic transmission (Table 141.3).

Neurotransmitters are packed in small vesicles in axon terminals only. But neuromodulators are generally

TABLE 141.3: Differences between neurotransmitters and neuromodulators

Sl No	Neurotransmitters	Neuromodulators
1	Propagate nerve impulse through synapse	Modify and regulate synaptic transmission
2	Packed in small synaptic vesicles	Packed in large synaptic vesicles
3	Found only in axon terminals	Found in all parts of the body
4	Generally, neuron has only one neurotransmitter	Neuron may have one or more neuromodulators
5	Act by changing the electric potential – depolarization or repolarization	Have diverse actions
6	Chemically, neurotransmitters are amino acids, amine or others	Chemically, neuromodulators are only peptides

packed in large synaptic vesicles, which are present in all parts of neuron like soma, dendrite, axon and nerve endings. Many neurons have one conventional neurotransmitter and one or more neuromodulators.

Few peptides like substance P (see above) act as neurotransmitters and neuromodulators.

Actions of Neuromodulators

Neurotransmitters affect the excitability of other neurons or other tissues (like muscle fiber) by producing **depolarization** or **hyperpolarization** through the receptors of ionic channels. But neuromodulators have diverse actions such as:

1. Regulation of synthesis, breakdown or reuptake of neurotransmitter
2. Excitation or inhibition of membrane receptors by acting independently or together with neurotransmitter
3. Control of gene expression
4. Regulation of local blood flow
5. Promotion of synaptic formation
6. Control of glial cell morphology
7. Regulation of behavior.

Chemistry of Neuromodulators

Generally the neuromodulators are **peptides.** So neuromodulators are often referred as **neuropeptides.** Almost all the peptides found in nervous tissues are neuromodulators.

Types of Neuromodulators

Neuromodulators are classified into two types:

1. Non-opioid peptides
2. Opioid peptides.

■ NON-OPIOID PEPTIDES

Non-opioid neuropeptides act by binding with G-protein coupled receptors. These neuropeptides are also called **non-opioid neuromodulators.** Non-opioid peptides are listed in Table 141.4.

■ OPIOID PEPTIDES

Peptides, which bind to opioid receptors are called **opioid peptides** (Table 141.5). Opioid peptides are also called opioid neuropeptides or opioid neuromodulators. Opioid receptors are the membrane proteins located in nerve endings in brain and GI tract. Opioid receptors are of three types μ, κ and δ. These proteins are called **opioid receptors** because of their affinity towards the opiate or morphine, which are derived from opium.

Opium is the juice of white **poppy *(Papaver somniferum).*** It is used as a narcotic to produce hallucinations and induce sleep. Opiate also induces sleep. **Morphine** is a powerful analgesic (pain reliever). Both opiate and morphine have high medicinal values, but are highly addictive.

These two substances act by binding with the receptor proteins (opioid receptors) for the natural neuropeptides. Natural neuropeptides are called **endogenous opioid peptides.**

Endogenous opioid peptides have opiate like activity and inhibit the neurons in the brain involved in pain sensation.

Opioid peptides are of three types:

i. Enkephalins
ii. Dynorphins
iii. Endorphins.

i. *Enkephalins*

Enkephalins are the natural opiate peptides recognized first in pig's brain. Derived from the precursor proenkephalin, these peptides are present in the nerve endings in many parts of forebrain, substantia gelatinosa of brainstem, spinal cord and GI tract. Two types of enkephalins are known, **leucine** enkephalin (YGGFL) and **methionine** enkephalin (YGGFM).

ii. *Dynorphins*

Dynorphins are derived from prodynorphin. Dynorphins are found in hypothalamus, posterior pituitary and duodenum. Dynorphins are of two types, α- and β-dynorphins.

iii. *Endorphins*

Endorphins are the large peptides derived from the precursor pro-opiomelanocortin. Endorphins are predominant in diencephalic region particularly hypothalamus and anterior and intermediate lobes of pituitary gland. Three types of endorphins are recognized, α-, β- and γ-endorphins.

■ COTRANSMISSION AND COTRANSMITTERS

Cotransmission is the release of many neurotransmitters from a single nerve terminal. Cotransmitters are the

TABLE 141.4: Non-opioid neuromodulators

Name	Site of secretion	Action
Bradykinin	Blood vessels, kidneys	Vasodilator
Substance P	Brain, spinal cord, retina peripheral nerves and intestine	Mediates pain. Regulates anxiety, stress, mood disorders, neurotoxicity, nausea and vomiting. Causes vasodilatation.
Secretin	Cerebral cortex, hypothalamus, thalamus, olfactory bulb, brainstem and small intestine	Inhibits gastric secretion and motility
CCK	Cerebral cortex, hypothalamus, retina and small intestine	Contracts gallbladder Inhibits gastric motility Increases intestinal motility
Gastrin	Hypothalamus, medulla oblongata, posterior pituitary and gastrointestinal (GI) tract	Increases gastric secretion and motility Stimulates islets in pancreas
VIP	Cerebral cortex, hypothalamus, retina and intestine	Causes vasodilatation
Motilin	Cerebral cortex, cerebellum, posterior pituitary and intestine	Stimulates intestinal motility
Neurotensin	Hypothalamus and retina	Inhibits pain sensation Decreases food intake
Vasopressin	Posterior pituitary, medulla oblongata and spinal cord	Causes vasoconstriction
Oxytocin	Posterior pituitary, medulla oblongata and spinal cord	Stimulates milk ejection and uterine contraction
CRH	Hypothalamus	Stimulates release of ACTH
GHRH	Hypothalamus	Stimulates release of growth hormone
GHRP	Hypothalamus	Stimulates release of GHRH
TRH	Hypothalamus, other parts of brain and retina	Stimulates release of thyroid hormones
Somatostatin	Hypothalamus, other parts of brain, substantia gelatinosa and retina	Inhibits growth hormone secretion Decreases food intake
GnRH	Hypothalamus, preganglionic autonomic nerve endings and retina	Inhibits gonadotropin secretion
Endothelin	Posterior pituitary, brainstem and endothelium	Causes vasoconstriction
Angiotensin II	Hypothalamus, brainstem and spinal cord	Causes vasoconstriction
ANP	Hypothalamus, brainstem and heart	Causes vasodilatation Increases sodium excretion
BNP	Hypothalamus and heart	Causes vasodilatation Increases sodium excretion
CNP	Brain, myocardium, endothelium of blood vessels, GI tract and kidneys	Causes vasodilatation Increases sodium excretion
Neuropeptide Y	Medulla, hypothalamus and small intestine	Increases food intake Causes vasoconstriction Increases enteric blood flow
Ghrelin	Hypothalamus, stomach, pituitary, kidney and placenta	Promotes GH release Induces appetite and food intake Stimulates gastric emptying

ACTH = Adrenocorticotropic hormone, ANP = Atrial natriuretic peptide, BNP = Brain natriuretic peptide, CCK = Cholecystokinin. CNP = C-type natriuretic peptide, CRH = Corticotropin-releasing hormone, GHRH = Growth hormone-releasing hormone, GHRP = Growth hormone-releasing polypeptide, GnRH = Gonadotropin-releasing hormone, TRH = Thyrotropin-releasing hormone, VIP = Vasoactive intestinal polypeptide.

TABLE 141.5: Opioid neuromodulators

Name	Site of secretion	Action
Enkephalins	Many parts of brain, substantia gelatinosa and retina	Inhibit pain sensation
Dynorphins	Hypothalamus, posterior pituitary and duodenum	
β-endorphin	Thalamus, hypothalamus, brainstem and retina	

neurotransmitter substances that are released in addition to primary transmitter at the nerve endings.

For many years, it was believed that each neuron releases only one neurotransmitter substance from its terminals. Now it is known that some of the neurons release many neurotransmitter substances. It is also believed that the additional neurotransmitters, i.e. the cotransmitters modulate the effects of primary neurotransmitters.

Some of the primary neurotransmitters act as cotransmitters in other nerve endings.

Examples of cotransmitters:

1. Calcitonin
2. Dopamine
3. Dynorphin
4. GABA
5. Gene-related peptide
6. Glutamate
7. Glycine
8. Neuropeptide Y
9. Substance P
10. Vasoactive intestinal polypeptide (VIP).

Reflex Activity

Chapter 142

- DEFINITION AND SIGNIFICANCE OF REFLEXES
- REFLEX ARC
- CLASSIFICATION OF REFLEXES
- SUPERFICIAL REFLEXES
- DEEP REFLEXES
- VISCERAL REFLEXES
- PATHOLOGICAL REFLEXES
- PROPERTIES OF REFLEXES
- RECIPROCAL INHIBITION AND RECIPROCAL INNERVATION
- REFLEXES IN MOTOR NEURON LESION

DEFINITION AND SIGNIFICANCE OF REFLEXES

Reflex activity is the response to a peripheral nervous stimulation that occurs without our consciousness. It is a type of **protective mechanism** and it protects the body from irreparable damages.

For example, when hand is placed on a hot object, it is withdrawn immediately. When a bright light is thrown into the eyes, eyelids are closed and pupil is constricted to prevent the damage of retina by entrance of excessive light into the eyes.

REFLEX ARC

Reflex arc is the anatomical nervous pathway for a reflex action. A simple reflex arc includes five components (Fig. 142.1).

1. *Receptor*

Receptor is the **end organ,** which receives the stimulus. When receptor is stimulated, impulses are generated in afferent nerve.

2. *Afferent Nerve*

Afferent or **sensory nerve** transmits sensory impulses from the receptor to center.

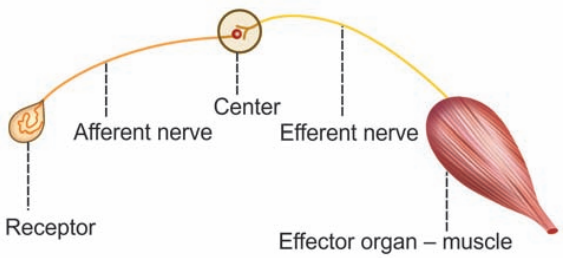

FIGURE 142.1: Simple reflex arc

3. *Center*

Center receives the sensory impulses via afferent nerve fibers and in turn, it generates appropriate motor impulses. Center is located in the brain or spinal cord.

4. *Efferent Nerve*

Efferent or **motor nerve** transmits motor impulses from the center to the effector organ.

5. *Effector Organ*

Effector organ is the structure such as muscle or gland where the activity occurs in response to stimulus.

Afferent and efferent nerve fibers may be connected directly to the center. In some places, one or more

neurons are interposed between these nerve fibers and the center. Such neurons are called **connector neurons** or **internuncial neurons** or **interneurons.**

CLASSIFICATION OF REFLEXES

Reflexes are classified by six different methods depending upon various factors. Different methods of classification are listed in Box 142.1.

BOX 142.1: Different methods to classify reflexes

Classification of reflexes
1. Depending upon whether inborn or acquired
2. Depending upon situation – anatomical classification
3. Depending upon purpose – physiological classification
4. Depending upon number of synapse
5. Depending upon whether visceral or somatic
6. Depending upon clinical basis

1. DEPENDING UPON WHETHER INBORN OR ACQUIRED REFLEXES

i. *Inborn Reflexes or Unconditioned Reflexes*

Unconditioned reflexes are the **natural reflexes,** which are present since the time of birth, hence the name inborn reflexes. Such reflexes do not require previous learning, training or conditioning. Best example is the secretion of saliva when a drop of honey is kept in the mouth of a newborn baby for the first time. The baby does not know the taste of honey, but still saliva is secreted.

ii. *Acquired Reflexes or Conditioned Reflexes*

Conditioned or acquired reflexes are the reflexes that are developed **after conditioning** or **training.** These reflexes are not inborn but, acquired after birth. Such reflexes need previous learning, training or conditioning. Example is the secretion of saliva by sight, smell, thought or hearing of a known edible substance.

2. DEPENDING UPON SITUATION – ANATOMICAL CLASSIFICATION

In this method, reflexes are classified depending upon the situation of the center.

i. *Cerebellar Reflexes*

Cerebellar reflexes are the reflexes which have their center in **cerebellum.**

ii. *Cortical Reflexes*

Cortical reflexes are the reflexes that have their center in **cerebral cortex.**

iii. *Midbrain Reflexes*

Midbrain reflexes are the reflexes which have their center in **midbrain.**

iv. *Bulbar or Medullary Reflexes*

Bulbar or medullary reflexes are the reflexes which have their center in **medulla oblongata.**

v. *Spinal Reflexes*

Reflexes having their center in the spinal cord are called spinal reflexes. Depending upon the segments involved, spinal reflexes are divided into three groups:

a. Segmental spinal reflexes
b. Intrasegmental spinal reflexes
c. Suprasegmental spinal reflexes.

3. DEPENDING UPON PURPOSE – PHYSIOLOGICAL CLASSIFICATION

In this method, reflexes are classified depending upon the purpose **(functional significance).**

i. *Protective Reflexes or Flexor Reflexes*

Protective reflexes are the reflexes which protect the body from **nociceptic (harmful) stimuli.** These reflexes are also called **withdrawal reflexes** or flexor reflexes. Protective reflexes involve flexion at different joints hence the name flexor reflexes.

ii. *Antigravity Reflexes or Extensor Reflexes*

Antigravity reflexes are the reflexes that protect the body against **gravitational force.** These reflexes are also called the extensor reflexes because, the extensor muscles contract during these reflexes resulting in extension at joints.

4. DEPENDING UPON THE NUMBER OF SYNAPSE

Depending upon the number of synapse in reflex arc, reflexes are classified into two types:

i. *Monosynaptic Reflexes*

Reflexes having only **one synapse** in the reflex arc are called monosynaptic reflexes. Stretch reflex is the best example for monosynaptic reflex and it is elicited due to the stimulation of muscle spindle.

ii. *Polysynaptic Reflexes*

Reflexes having **more than one** synapse in the reflex arc are called polysynaptic reflexes. Flexor reflexes (withdrawal reflexes) are the polysynaptic reflexes.

■ 5. DEPENDING UPON WHETHER SOMATIC OR VISCERAL REFLEXES

i. *Somatic Reflexes*

Somatic reflexes are the reflexes, for which the reflex arc is formed by **somatic nerve fibers.** These reflexes involve the participation of skeletal muscles. And there may be flexion or extension at different joints during these reflexes.

ii. *Visceral or Autonomic Reflexes*

Visceral or autonomic reflexes are the reflexes, for which at least a part of reflex arc is formed by **autonomic nerve fibers.** These reflexes involve participation of smooth muscle or cardiac muscle. Visceral reflexes include pupillary reflexes, gastrointestinal reflexes, cardiovascular reflexes, respiratory reflexes, etc.

Some reflexes like swallowing, coughing or vomiting are considered as visceral reflexes. However, these reflexes involve some participation of skeletal muscles also.

■ 6. DEPENDING UPON CLINICAL BASIS

Depending upon the clinical basis, reflexes are classified into four types:

i. Superficial reflexes
ii. Deep reflexes
iii. Visceral reflexes
iv. Pathological reflexes.

■ SUPERFICIAL REFLEXES

Superficial reflexes are the reflexes, which are elicited from the surface of the body. Superficial reflexes are of two types: mucus membrane reflexes and skin reflexes.

■ 1. MUCOUS MEMBRANE REFLEXES

Mucous membrane reflexes arise from the mucus membrane. Details of mucus membrane reflexes are listed in Table 142.1.

■ 2. CUTANEOUS REFLEXES OR SKIN REFLEXES

Cutaneous reflexes are elicited from skin by the stimulation of cutaneous receptors. Details of these reflexes are given in Table 142.2.

■ DEEP REFLEXES

Deep reflexes are elicited from deeper structures beneath the skin like tendon. These reflexes are otherwise known as **tendon reflexes.** Details of these are given in Table 142.3.

■ VISCERAL REFLEXES

Visceral reflexes are the reflexes arising from **pupil** and **visceral organs.** Other details of visceral reflexes are already given above.

TABLE 142.1: Superficial mucous membrane reflexes

Reflex	Stimulus	Response	Afferent Nerve	Center	Efferent Nerve
1. Corneal reflex	Irritation of cornea	Blinking of eye (closure of eyelids)	V cranial nerve	Pons	VII cranial nerve
2. Conjunctival reflex	Irritation of conjunctiva	Blinking of eye	V cranial nerve	Pons	VII cranial nerve
3. Nasal reflex (sneezing reflex)	Irritation of nasal mucus membrane	Sneezing	V cranial nerve	Motor nucleus of V cranial nerve	X cranial nerve and upper cervical nerves
4. Pharyngeal reflex	Irritation of pharyngeal mucus membrane	Retching or gagging (opening of mouth)	IX cranial nerve	Nuclei of X cranial nerve	X cranial nerve
5. Uvular reflex	Irritation of uvula	Raising of uvula	IX cranial nerve	Nuclei of X cranial nerve	X cranial nerve

TABLE 142.2: Superficial cutaneous reflexes

Reflex	Stimulus	Response	Center – spinal segments involved
1. Scapular reflex	Irritation of skin at the interscapular space	Contraction of scapular muscles and drawing in of scapula	C5 to T1
2. Upper abdominal reflex	Stroking the abdominal wall below the costal margin	Ipsilateral contraction of abdominal muscle and movement of umbilicus towards the site of stroke	T6 to T9
3. Lower abdominal reflex	Stroking the abdominal wall at umbilical and iliac level	Ipsilateral contraction of abdominal muscle and movement of umbilicus towards the site of stroke	T10 to T12
4. Cremasteric reflex	Stroking the skin at upper and inner aspect of thigh	Elevation of testicles	L1, L2
5. Gluteal reflex	Stroking the skin over glutei	Contraction of glutei	L4 to S1,2
6. Plantar reflex	Stroking the sole	Plantar flexion and adduction of toes	L5 to S2
7. Bulbocavernous reflex	Stroking the dorsum of glans penis	Contraction of bulbocavernosus	S3, S4
8. Anal reflex	Stroking the perianal region	Contraction of anal sphincter	S4, S5

TABLE 142.3: Deep reflexes

Reflex	Stimulus	Response	Center – spinal segments involved
1. Jaw jerk	Tapping middle of the chin with slightly opened mouth	Closure of mouth	Pons – V cranial nerve
2. Biceps jerk	Percussion of biceps tendon	Flexion of forearm	C5, C6
3. Triceps jerk	Percussion of triceps tendon	Extension of forearm	C6 to C8
4. Supinator jerk or radial periosteal reflex	Percussion of tendon over distal end (styloid process) of radius	Supination and flexion of forearm	C7, C8
5. Wrist tendon or finger flexion reflex	Percussion of wrist tendons	Flexion of corresponding finger	C8, T1
6. Knee jerk or patellar tendon reflex	Percussion of patellar ligament	Extension of leg	L2 to L4
7. Ankle jerk or Achilles tendon reflex	Percussion of Achilles tendon	Plantar flexion of foot	L5 to S2

Following are the visceral reflexes:

1. Pupillary reflexes
2. Oculocardiac reflex
3. Carotid sinus reflex.

■ PUPILLARY REFLEXES

Pupillary reflexes are the reflexes in which, the size of pupil is altered.

Pupillary reflexes are:

i. Light reflex
ii. Accommodation reflex
iii. Ciliospinal reflex.

i. *Light Reflex*

When retina of the eye is stimulated by a sudden flash of light, **constriction of pupil occurs.** It is called light reflex.

Light reflex of two types:

a. Direct light reflex, in which stimulation of retina in one eye by flash of light causes constriction of pupil in the same eye

b. Indirect or consensual light reflex, in which stimulation of retina in one eye by flash of light causes simultaneous constriction of pupil in the other eye also.

ii. *Accommodation Reflex*

While eyes are fixed on a distant object and if another object is brought in front of the eye (near the eye) the vision shifts form **far object** to **near object.** During that time some changes occur in the eyes.

Changes during accommodation reflex are:

a. Constriction of pupil
b. Convergence of eyeball
c. Increase in anterior curvature of lens.

iii. *Ciliospinal Reflex*

Ciliospinal reflex is the **dilatation of pupil** due to stimulation of skin over the neck.

More details of pupillary reflexes are given in Chapter 169.

■ OCULOCARDIAC REFLEX

Oculocardiac reflex is the reflex, in which **heart rate decreases** due to the pressure applied over eyeball.

■ CAROTID SINUS REFLEX

Carotid sinus reflex is the **decrease in heart rate** and blood pressure caused by pressure over carotid sinus in neck due to tight collar.

■ PATHOLOGICAL REFLEXES

Pathological reflexes are the reflexes that are elicited only in pathological conditions. Well-known pathological reflexes are:

1. Babinski sign
2. Clonus
3. Pendular movements.

■ BABINSKI SIGN

Abnormal plantar reflex is called Babinski sign. It is also called Babinski reflex or phenomenon. It is named after the discoverer **Joseph Babinski.** In normal plantar reflex, a gentle scratch over the outer edge of the sole of foot causes plantar flexion and adduction of all toes. But in Babinski sign, there is dorsiflexion of great toe and fanning of other toes.

When Babinski reflex is present, the condition is commonly called Babinski **positive sign** and when it is negative, the condition is called Babinski **negative sign.**

Babinski sign is present in **upper motor neuron lesion.** Physiological conditions when Babinski sign is present are infancy and deep sleep. It is present in infants because of non-myelination of pyramidal tracts.

■ CLONUS

Clonus is a series of rapid and repeated involuntary jerky movements, which occur while eliciting a deep reflex. When a deep reflex is elicited in a normal person, the contractions of a muscle or group of muscles are smooth and continuous. But clonus occurs when the deep reflexes are exaggerated due to hypertonicity of muscles in **pyramidal tract lesion.** Clonus is well seen in calf muscles producing ankle clonus and quadriceps producing patella clonus.

Ankle Clonus

Ankle clonus is the repeated rhythmical contractions of calf muscles caused by sudden dorsiflexion of foot.

Repeated rhythmical contractions of calf muscles lead to a series of rhythmic plantar flexion at ankle joint. Sudden dorsiflexion of foot is done by supporting patient's knee in a slightly flexed position.

Patellar Clonus

Patellar clonus is the rhythmic jerky movements of patella produced by grasping it between thumb and index finger of the examiner and pushing it down forcibly towards the foot. It is caused by clonic contractions of quadriceps muscle.

■ PENDULAR MOVEMENTS

Pendular movements are the slow oscillatory movements (instead of brisk movements) that are developed while eliciting a tendon jerk. Unlike clonus, pendular movements occur because of hypotonicity of muscles. Pendular movements are very common while eliciting the knee jerk or patellar tendon reflex in the patients affected by cerebellar lesion.

A tap on the patellar tendon when leg is hanging freely causes a brisk extension of leg due to the contraction of quadriceps muscle (knee jerk). In normal conditions, after the extension, the leg returns back to resting position immediately. In **cerebellar lesion,** the leg swings forwards and backwards several times before coming to rest. Such movements are similar to movements of **clock's pendulum** hence the name pendular movements.

PROPERTIES OF REFLEXES

1. ONE WAY CONDUCTION (BELL-MAGENDIE LAW)

During any reflex activity, impulses are transmitted in only **one direction** through the reflex arc as per Bell-Magendie law. The impulses pass from receptors to center and then from center to effector organ.

2. REACTION TIME

Reaction time is the time interval between application of stimulus and the onset of reflex. It depends upon the length of afferent and efferent nerve fibers, velocity of impulse through these fibers and central delay. Central delay is the delay at the synapse. It is also called **synaptic delay.**

3. SUMMATION

Refer Chapter 140 for details of summation. Summation in reflex action is of two types:

i. *Spatial Summation*

When two afferent nerve fibers supplying a muscle are stimulated separately with subliminal stimulus, there is no response. But the muscle contracts when both the nerve fibers are stimulated together with same strength of stimulus. It is called spatial summation.

ii. *Temporal Summation*

When one nerve fiber is stimulated repeatedly with subliminal stimuli, these stimuli are summed up to give response in the muscle. It is called temporal summation.

Thus, both spatial summation and temporal summation play an important role in the **facilitation of responses** during the reflex activity.

4. OCCLUSION

Occlusion is demonstrated in a flexor reflex involving a muscle, which is innervated by two motor nerves. These nerves can be called A and B. When both the nerves, A and B, are stimulated simultaneously, the tension developed by the muscle is less than the sum of the tension developed when each nerve is stimulated separately.

For example, if nerve A is stimulated alone, the arbitrary unit of tension developed is 9. If the nerve B is stimulated then 9 units of tension is developed. So, the sum of tension developed when the nerves A and B are separately stimulated = 9 + 9 = 18 units (Fig. 142.2).

But, when both A and B are stimulated together, the tension produced is (A + B) = 12 units. Thus, the tension here is less than sum of tension produced when A and B were stimulated separately. This phenomenon is called occlusion. Occlusion is due to the **overlapping** of the nerve fibers during the distribution.

5. SUBLIMINAL FRINGE

In some reflexes involving the muscle with two nerve fibers, the tension developed by simultaneous stimulation of two nerves is greater than the sum of tension produced by the stimulation of these nerves separately.

For example, if nerve A is stimulated alone, the arbitrary unit of tension developed by muscle = 3 units (Fig. 142.3). If nerve B is stimulated alone, the tension produced = 3 units. So, the sum of tension developed, if nerves A and B are stimulated separately = 3 + 3 = 6 units. When both the nerves A and B were stimulated together, the tension developed is (A + B) = 12 units. Thus, the tension here is greater than the sum of tension produced, if A and B are separately stimulated. This phenomenon is called subliminal fringe. It is due to the effect of **spatial summation.**

6. RECRUITMENT

Recruitment is defined as the successive activation of additional motor units with progressive increase in force of muscular contraction.

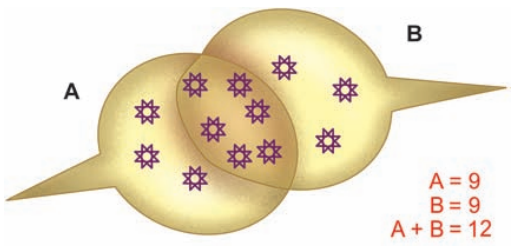

FIGURE 142.2: Occlusion

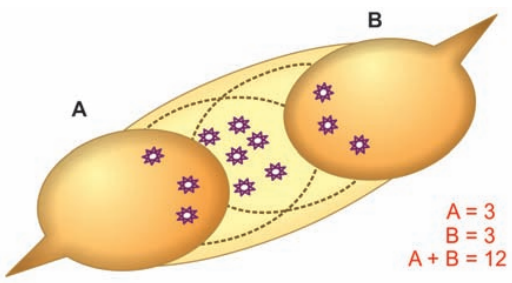

FIGURE 142.3: Subliminal fringe

When an excitatory nerve is stimulated for a long time, there is a gradual increase in the response of reflex activities. It is due to the activation of more and more motor neurons. Recruitment is similar to the effect of **temporal summation.**

Indefinite increase in response does not produce unlimited recruitment. A **plateau** is reached. Thus, there is a limit to the number of motor neurons, which are recruited. So, beyond certain limit, the prolongation of stimulation does not increase the response.

7. AFTER DISCHARGE

After discharge is the persistence or continuation of response for some time even after cessation of stimulus. When a reflex action is elicited continuously for sometime and then the stimulation is stopped, the reflex activity (contraction) will be continued for sometime even after the stoppage of the stimulus. It is because of the discharge of impulses from the center even after stoppage of stimulus. Internuncial neurons, which continue to transmit afferent impulses even after stoppage of stimulus are responsible for after discharge.

8. REBOUND PHENOMENON

Reflex activities can be forcefully inhibited for some time. But, when the inhibition is suddenly removed, the reflex activity becomes more forceful than before inhibition. It is called rebound phenomenon. Reason for this state of over excitation is not known.

9. FATIGUE

When a reflex activity is continuously elicited for a long time, the response is reduced slowly and at one stage, the response does not occur. This type of failure to give response to the stimulus is called fatigue. Center or the synapse of the reflex arc is the **first seat** of fatigue.

RECIPROCAL INHIBITION AND RECIPROCAL INNERVATION

RECIPROCAL INHIBITION

Reciprocal inhibition is one of the important features of both flexor and extensor reflexes. Usually, excitation of one group of muscles is associated with inhibition of another, i.e. antagonistic group of muscles on the same side. For example, when a flexor reflex is elicited, the flexor muscles are excited (contracted) and the extensor muscles are inhibited (relaxed) in that side. This phenomenon is called the reciprocal inhibition.

Reciprocal inhibition occurs because of the reciprocal innervation.

RECIPROCAL INNERVATION – SHERRINGTON LAW

Neural mechanism involved in reciprocal inhibition was postulated by **Sherrington.** Hence, it is called Sherrington law of reciprocal innervation. According to this law, the reciprocal inhibition is due to segmental arrangement of afferent and efferent connections in the spinal cord. Afferent nerve fibers, which evoke flexor reflex in a limb, have connections with motor neurons supplying flexors and the motor neurons supplying the extensors of same side. Afferent nerve excites the motor neurons, which supply the flexors.

Simultaneously, it also inhibits the motor neurons supplying extensors through an interneuron. Accordingly, the flexor muscles contract and extensor muscles relax resulting in flexion of the limb (Fig. 142.4).

CROSSED EXTENSOR REFLEX

Crossed extensor reflex is the withdrawal reflex in which the flexors of the withdrawing limb are excited (contracting) and extensors are inhibited (relaxed), while the opposite occurs in the other limb. For example, while eliciting a flexor reflex activity in a limb, that limb is flexed. Simultaneously the opposite limb is extended.

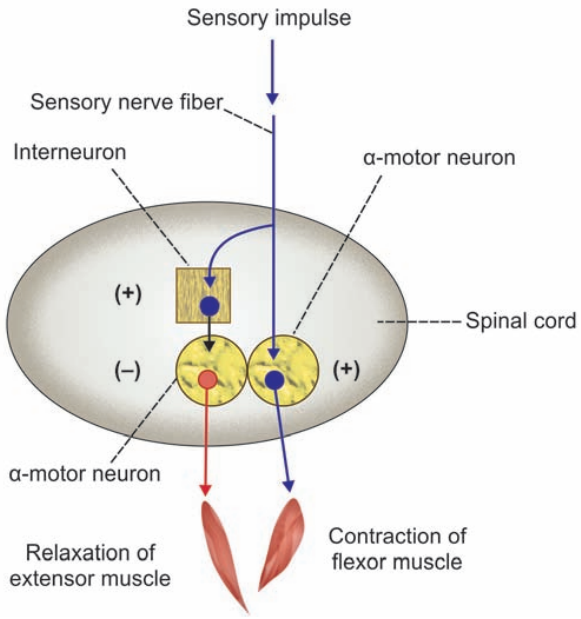

FIGURE 142.4: Reciprocal inhibition
(+) = Excitation. (–) = Inhibition.

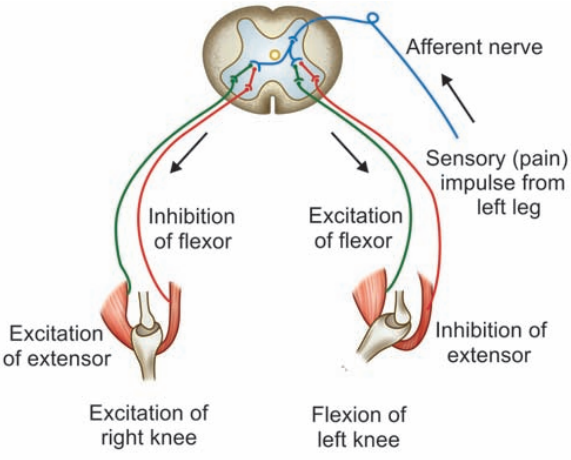

FIGURE 142.5: Crossed extensor reflex. Green lines indicate excitation and red lines indicate inhibition.

Flexors are excited and extensors are inhibited in this limb, but in the opposite limb, the flexors are inhibited and extensors are excited. This type of crossed extensor reflex is because of reciprocal inhibition. It occurs in upper motor neuron lesion.

Crossed extensor reflex is demonstrated in a spinal animal. When one limb of the animal is pinched, it is withdrawn, i.e. flexed. But the opposite limb is extended (Fig. 142.5).

■ SIGNIFICANCE OF RECIPROCAL INHIBITION

Reciprocal inhibition and reciprocal innervation are very important in spinal reflexes, which are involved in **locomotion.** It helps in the forward movement of one limb while causing the backward movement of the opposite limb.

■ REFLEXES IN MOTOR NEURON LESION

■ UPPER MOTOR NEURON LESION

During upper motor neuron lesion, all the superficial reflexes are lost. Deep reflexes are exaggerated and the Babinski sign is positive (Chapter 144).

■ LOWER MOTOR NEURON LESION

During lower motor lesion, all the superficial and deep reflexes are lost (Chapter 144).

Spinal Cord

Chapter 143

- INTRODUCTION
- GRAY MATTER
- WHITE MATTER
- TRACTS IN SPINAL CORD
- ASCENDING TRACTS
- DESCENDING TRACTS
- APPLIED PHYSIOLOGY

INTRODUCTION

Situation and Extent

Spinal cord lies loosely in the **vertebral canal.** It extends from **foramen magnum** where it is continuous with medulla oblongata, above and up to the lower border of first lumbar vertebra below.

Coverings

Spinal cord is covered by sheaths called **meninges,** which are membranous in nature. Meninges are **dura mater, pia mater** and **arachnoid mater.** These coverings continue as coverings of brain. Meninges are responsible for protection and nourishment of the nervous tissues.

Shape and Length

Spinal cord is cylindrical in shape. Length of the spinal cord is about 45 cm in males and about 43 cm in females.

Enlargements

Spinal cord has two spindle-shaped swellings, namely **cervical** and **lumbar enlargements.** These two portions of spinal cord innervate upper and lower extremities respectively.

Conus Medullaris and Filum Terminale

Below the lumbar enlargement, spinal cord rapidly narrows to a cone-shaped termination called **conus medullaris.** A slender non-nervous filament called **filum terminale** extends from conus medullaris downward to the fundus of the dural sac at the level of second sacral vertebra.

Segments

Spinal cord is made up of 31 segments, which are listed in Box 143.1. In fact, spinal cord is a continuous structure. Appearance of the segment is by nerves arising from spinal cord, which are called spinal nerve.

Spinal Nerves

Segments of spinal cord correspond to 31 pairs of spinal nerves in a symmetrical manner. The spinal nerves are listed in Box 143.1.

BOX 143.1: Segments of spinal cord and spinal nerves

Spinal segments/Spinal nerves		
1. Cervical segments/Cervical spinal nerves	=	8
2. Thoracic segments/Thoracic spinal nerves	=	12
3. Lumbar segments/Lumbar spinal nerves	=	5
4. Sacral segments/Sacral spinal nerves	=	5
5. Coccygeal segment/Coccygeal spinal nerves	=	1
Total	=	31

Nerve Roots

Each spinal nerve is formed by an **anterior (ventral) root** and a **posterior (dorsal) root.** Both the roots on

either side leave the spinal cord and pass through the corresponding **intervertebral foramina.** The first cervical spinal nerves pass through a foramen between occipital bone and first vertebra, which is called **atlas.** Cervical and thoracic roots are shorter whereas, the lumbar and sacral roots are longer. Long nerves descend in dural sac to reach their respective intervertebral foramina. This bundle of descending roots surrounding the filum terminale resembles the tail of horse. Hence, it is called cauda equina.

Fissure and Sulci

On the anterior surface of spinal cord, there is a deep furrow known as **anterior median fissure.** Depth of this fissure is about 3 mm. Lateral to the anterior median fissure on either side, there is a slight depression called the **anterolateral sulcus.** It denotes the exit of anterior nerve root. On the posterior aspect, there is a depression called **posterior median sulcus.** This sulcus is continuous with a thin glial partition called the **posterior median septum.** It extends inside the spinal cord for about 5 mm and reaches the gray matter.

On either side, lateral to posterior median sulcus, there is **posterior intermediate sulcus.** It is continuous with **posterior intermediate septum,** which extends for about 3 mm into the spinal cord. Lateral to the posterior intermediate sulcus, is the **posterolateral sulcus.** This denotes the entry of posterior nerve root.

Internal Structure of Spinal Cord

Neural substance of spinal cord is divided into inner gray matter and outer white matter (Fig. 143.1).

■ GRAY MATTER OF SPINAL CORD

Gray matter of spinal cord is the collection of nerve cell bodies, dendrites and parts of axons. It is placed centrally in the form of **wings of the butterfly** and it resembles the letter 'H'. Exactly in the center of gray matter, there is a canal called the **spinal canal.**

Ventral and the dorsal portions of each lateral half of gray matter are called ventral (anterior) and dorsal (posterior) gray horns respectively. In addition, the gray matter forms a small projection in between the anterior and posterior horns in all thoracic and first two lumbar segments. It is called the lateral gray horn. Part of the gray matter anterior to central canal is called the **anterior gray commissure** and part of gray matter posterior to the central canal is called **posterior gray commissure.**

Neurons in Gray Matter of Spinal Cord

Gray matter contains two types of multipolar neurons:

1. *Golgi type I neurons*

Golgi type I neurons have **long axons** and are usually found in anterior horns. Axons of these neurons form the long tracts of spinal cord.

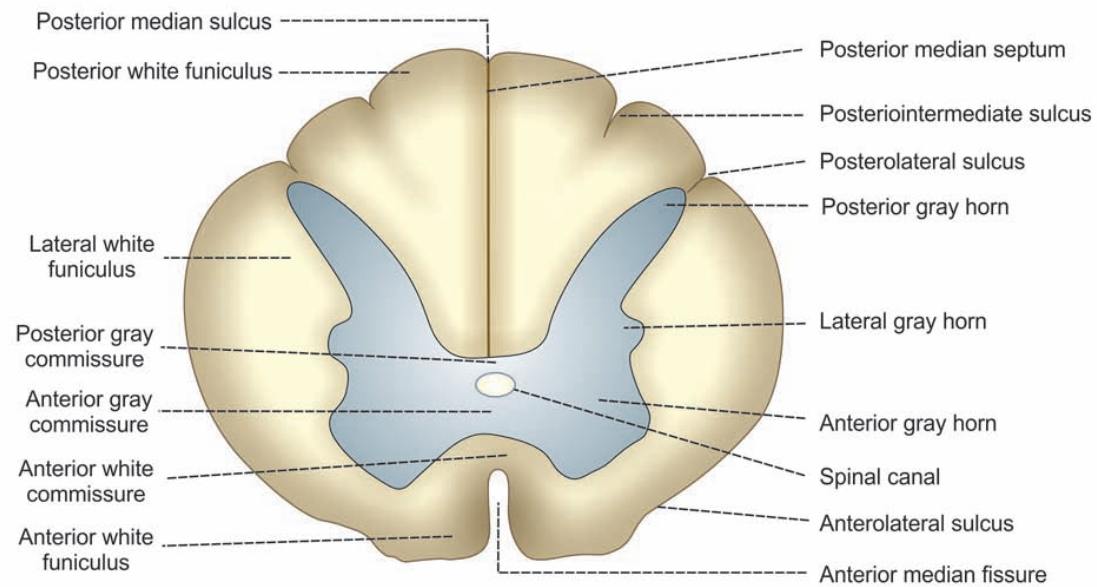

FIGURE 143.1: Section of spinal cord: thoracic segment

Golgi type II neurons

Golgi type II neurons have **short axons,** which are found mostly in posterior horns. Axons of these neurons pass towards the anterior horn of same side or opposite side.

Organization of Neurons in Gray Matter

Organization of neurons in the gray matter of spinal cord is described in two methods:

1. Nuclei or columns
2. Laminae or layers (Fig. 143.2).

■ NUCLEI

Clusters of neurons are present in the form of nuclei or cell columns in gray matter. Advantage of this method is that different nuclei are easily distinguished. Disadvantage is that some neurons like internuncial neurons, which are outside the distinct nuclei are not included.

Nuclei in Posterior Gray Horn

Posterior gray horn contains the nuclei of sensory neurons, which receive impulses from various receptors of the body through posterior nerve root fibers. There are four types of nuclei of sensory neurons:

1. *Marginal nucleus*

Marginal nucleus is also called **posteromarginal nucleus, marginal zone nucleus** or **border nucleus.** It covers the very tip of posterior gray horn and it is found in all levels of spinal cord.

2. *Substantia gelatinosa of Rolando*

Substantia gelatinosa of Rolando is a cap-like gelatinous material at the apex of posterior horn situated in all levels of spinal cord. It is formed by small neurons.

3. *Chief sensory nucleus or nucleus proprius*

Chief sensory nucleus is situated in the posterior gray horn ventral to substantia gelatinosa. It is a poorly defined cell column located in all segments of spinal cord.

4. *Dorsal nucleus of Clarke*

Clarke nucleus is also called **Clarke column of cells** and it is the collection of well-defined neurons. It occupies the basal portion of posterior horn. This nucleus is found in spinal segments between C8 and L3 only.

Nuclei in Lateral Gray Horn

Lateral gray horn has cluster of neurons called intermediolateral nucleus. The neurons of this nucleus give rise to sympathetic preganglionic fibers, which leave the spinal cord through the anterior nerve root. Intermediolateral nucleus extends between T1 and L2 segments of spinal cord.

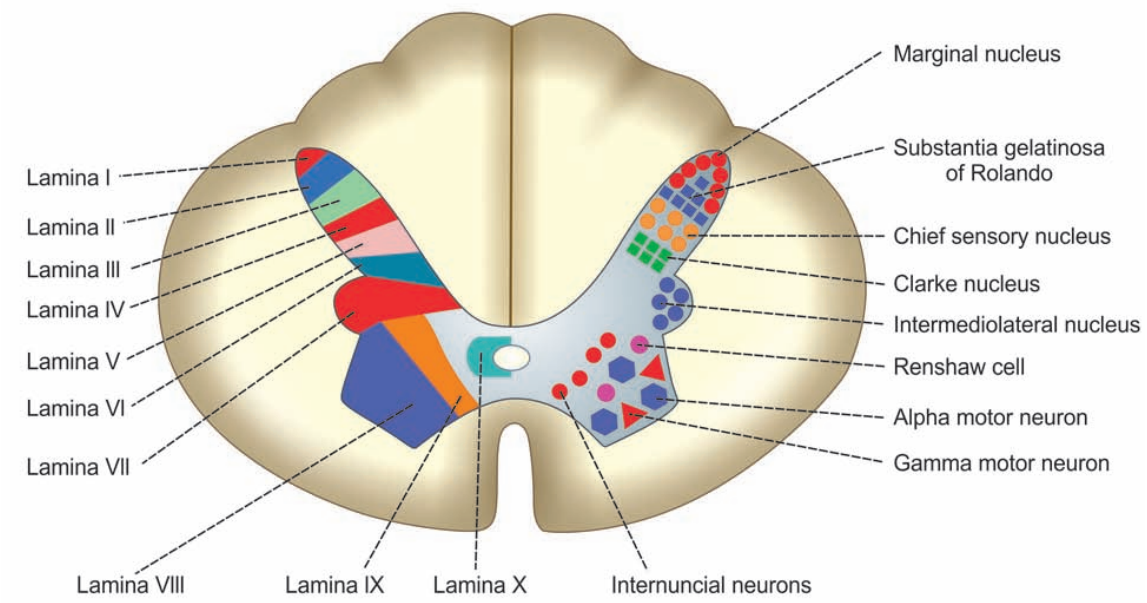

FIGURE 143.2: Neurons in gray horn of spinal cord: thoracic segment

Nuclei in Anterior Gray Horn

Anterior gray horn contains the nuclei of lower motor neurons, which are involved in motor function. These nuclei are present in almost all the levels of spinal cord. Three types of motor neurons are present in lower motor neuron nuclei:

1. *Alpha motor neurons*

Alpha motor neurons are large and multipolar cells. Axons of these neurons leave the spinal cord through the anterior root and end in groups of skeletal muscle fibers called **extrafusal fibers.**

2. *Gamma motor neurons*

Gamma motor neurons are smaller cells scattered among alpha motor neurons. These neurons send axons to **intrafusal fibers** of the muscle spindle.

3. *Renshaw cells*

These cells are also smaller in size. Renshaw cells are the **inhibitory neurons,** which play an important role in **synaptic inhibition** at the spinal cord (Chapter 140).

■ LAMINAE

Neurons of gray matter are distributed in laminae or layers. Each lamina consists of neurons of different size and shape. This cytoarchitectural lamination was identified in 1950 by **Brian Burke** and **Rexed.** He classified the neurons in 10 laminae based on his observation on sections of brain in a neonatal cat. Laminae are also called **Rexed laminae.**

Advantage of this method is that all the neurons of gray horn are included. Disadvantage is that it is difficult to distinguish the laminae from one another.

Laminae in Posterior Gray Horn

Laminae I to VI constitute the posterior gray horn. These laminae contain nuclei of sensory neurons, which are concerned with sensory functions.

Nuclei present in the laminae of posterior gray horn

Marginal nucleus	:	Lamina I
Substantial gelatinosa of Rolando	:	Laminae II and III
Chief sensory nucleus	:	Laminae III, IV and V
Dorsal nucleus of Clarke	:	Lamina VI

Lamina in Lateral Gray Horn

Lateral gray horn contains only one lamina, the lamina VII. It contains intermediolateral nucleus.

Laminae in Anterior Gray Horn

Laminae VIII and IX form the anterior gray horn. These laminae contain nuclei of motor neurons, which are concerned with motor functions.

Neurons present in the laminae of anterior gray horn

Motor internuncial neurons, which are also called interneurons	:	Lamina VIII
Motor neurons	:	Lamina IX

Lamina Around Central Canal

There is only one lamina around the center of the spinal canal, the lamina X. It contains neuroglia, which form the supporting tissue.

■ WHITE MATTER OF SPINAL CORD

White matter of spinal cord surrounds the gray matter. It is formed by the bundles of both myelinated and non-myelinated fibers, but predominantly the myelinated fibers. Anterior median fissure and posterior median septum divide the entire mass of white matter into two lateral halves. The band of white matter lying in front of anterior gray commissure is called **anterior white commissure** (Fig. 143.2).

Each half of the white matter is divided by the fibers of anterior and posterior nerve roots into three white columns or funiculi:

I. *Anterior or Ventral White Column*

Ventral white column lies between the anterior median fissure on one side and anterior nerve root and anterior gray horn on the other side. It is also called **anterior** or **ventral funiculus.**

II. *Lateral White Column*

Lateral white column is present between the anterior nerve root and anterior gray horn on one side and posterior nerve root and posterior gray horn on the other side. It is also called **lateral funiculus.**

III. *Posterior or Dorsal White Column*

Dorsal white column is situated between the posterior nerve root and posterior gray horn on one side and posterior median septum on the other side. It is also called **posterior or dorsal funiculus.**

■ TRACTS IN SPINAL CORD

Groups of nerve fibers passing through spinal cord are known as tracts of the spinal cord. The spinal tracts are

divided into two main groups. They are:

1. Short tracts
2. Long tracts.

1. *Short Tracts*

Fibers of the short tracts connect different parts of spinal cord itself.

Short tracts are of two types:

i. **Association or intrinsic tracts,** which connect adjacent segments of spinal cord on the same side
ii. **Commissural tracts,** which connect opposite halves of same segment of spinal cord.

2. *Long Tracts*

Long tracts of spinal cord, which are also called **projection tracts,** connect the spinal cord with other parts of central nervous system.

Long tracts are of two types:

i. Ascending tracts, which carry sensory impulses from the spinal cord to brain
ii. Descending tracts, which carry motor impulses from brain to the spinal cord.

■ ASCENDING TRACTS OF SPINAL CORD

Ascending tracts of spinal cord carry the impulses of various sensations to the brain.

Pathway for each sensation is formed by two or three groups of neurons, which are:

1. First order neurons
2. Second order neurons
3. Third order neurons.

First Order Neurons

First order neurons receive sensory impulses from the receptors and send them to sensory neurons present in the posterior gray horn of spinal cord through their fibers. Nerve cell bodies of these neurons are located in the **posterior nerve root ganglion.**

Second Order Neurons

Second order neurons are the sensory neurons present in the posterior gray horn. Fibers from these neurons form the ascending tracts of spinal cord. These fibers carry sensory impulses from spinal cord to different brain areas below cerebral cortex **(subcortical areas)** such as thalamus.

All the ascending tracts are formed by fibers of second order neurons of the sensory pathways except the ascending tracts in the posterior white funiculus, which are formed by the fibers of first order neurons.

Third Order Neurons

Third order neurons are in the **subcortical areas.** Fibers of these neurons carry the sensory impulses from subcortical areas to cerebral cortex.

Ascending tracts situated in different white funiculi are listed in Table 143.1 and their features are given in Table 143.2.

■ 1. ANTERIOR SPINOTHALAMIC TRACT

Anterior spinothalamic tract is formed by the fibers of second order neurons of the pathway for **crude touch sensation** (Figs. 143.3 and 143.4).

Situation

Anterior spinothalamic tract is situated in **anterior white funiculus** near the periphery.

Origin

Fibers of anterior spinothalamic tract arise from the neurons of **chief sensory nucleus** of posterior gray horn, which form the **second order neurons** of the crude touch pathway. First order neurons are situated in the posterior nerve root ganglia. These neurons receive the impulses of crude touch sensation from the pressure receptors. Axons of the first order neurons reach the chief sensory nucleus through the posterior nerve root.

Course

Anterior spinothalamic tract contains **crossed fibers.** After taking origin, these fibers cross obliquely in the anterior white commissure and enter the anterior white column of opposite side. Here, the fibers ascend through other segments of spinal cord and brainstem (medulla, pons and midbrain) and reach thalamus.

TABLE 143.1: List of ascending tracts of spinal cord

White column	Tract
Anterior white column	1. Anterior spinothalamic tract
Lateral white column	1. Lateral spinothalamic tract 2. Ventral spinocerebellar tract 3. Dorsal spinocerebellar tract 4. Spinotectal tract 5. Fasiculus dorsolateralis 6. Spinoreticular tract 7. Spino-olivary tract 8. Spinovestibular tract
Posterior white column	1. Fasciculus gracilis 2. Fasciculus cuneatus 3. Comma tract of Schultze

TABLE 143.2: Ascending tracts of spinal cord

Situation	Tract	Origin	Course	Termination	Function
Anterior white column	1. Anterior spinothalamic tract	Chief sensory nucleus	Crossing in spinal cord Forms spinal lemniscus	Ventral posterolateral nucleus of thalamus	Crude touch sensation
Lateral white column	1. Lateral spinothalamic tract	Substantia gelatinosa	Crossing in spinal cord Forms spinal lemniscus	Ventral posterolateral nucleus of thalamus	Pain and temperature sensations
	2. Ventral spinocerebellar tract	Marginal nucleus	Crossing in spinal cord	Anterior lobe of cerebellum	Subconscious kinesthetic sensations
	3. Dorsal spinocerebellar tract	Clarke nucleus	Uncrossed fibers	Anterior lobe of cerebellum	Subconscious kinesthetic sensations
	4. Spinotectal tract	Chief sensory nucleus	Crossing in spinal cord	Superior colliculus	Spinovisual reflex
	5. Fasiculus dorsolateralis	Posterior nerve root ganglion	Component of lateral spinothalamic tract	Substantia gelatinosa	Pain and temperature sensations
	6. Spinoreticular tract	Intermediolateral cells	Crossed and uncrossed fibers	Reticular formation of brainstem	Consciousness and awareness
	7. Spino-olivary tract	Non-specific	Uncrossed fibers	Olivary nucleus	Proprioception
	8. Spinovestibular tract	Non-specific	Crossed and uncrossed fibers	Lateral vestibular nucleus	Proprioception
Posterior white column	1. Fasciculus gracilis	Posterior nerve root ganglia	Uncrossed fibers No synapse in spinal cord	Nucleus gracilis in medulla	Tactile sensation Tactile localization Tactile discrimination Vibratory sensation Conscious kinesthetic sensation Stereognosis
	2. Fasciculus cuneatus	Posterior nerve root ganglia	Uncrossed fibers No synapse in spinal cord	Nucleus cuneatus in medulla	

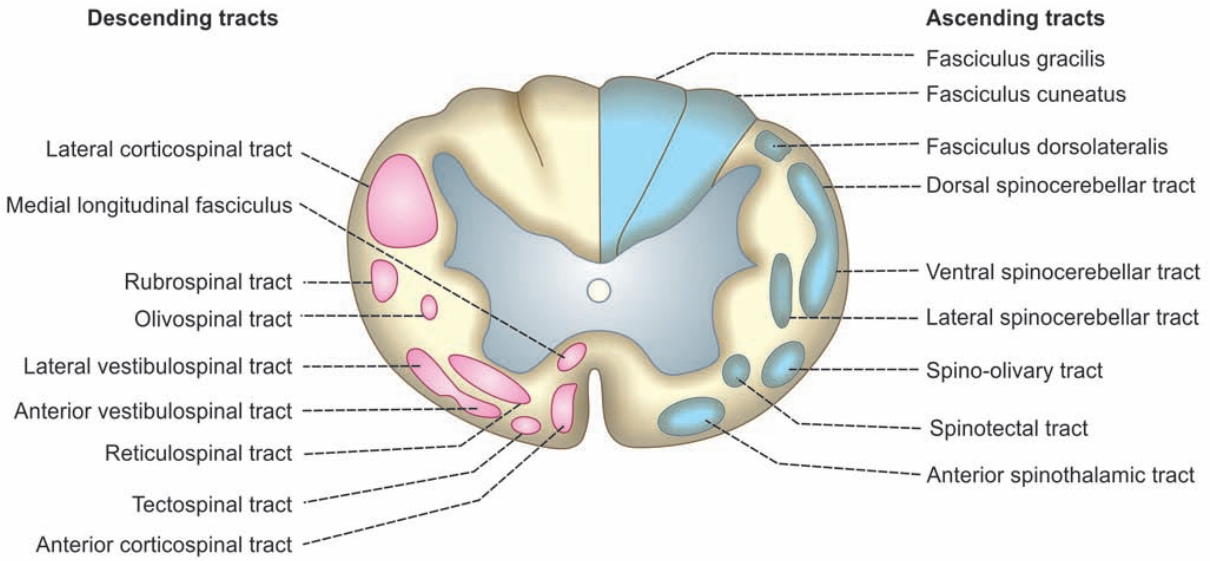

FIGURE 143.3: Tracts of spinal cord

Few fibers of this tract ascend in posterior gray horn for 2 or 3 segments in the same side and then cross over to the anterior white column of opposite side.

While ascending through brainstem, the number of fibers is considerably reduced since some of the fibers form the collaterals and reach the reticular formation of brainstem.

Termination

Fibers of anterior spinothalamic tract terminate in the **ventral posterolateral nucleus** of **thalamus.** Neurons of this thalamic nucleus form third order neurons of the pathway. Fibers from thalamic nucleus carry the impulses to somesthetic area (sensory cortex) of cerebral cortex.

Function

Anterior spinothalamic tract carries impulses of **crude touch** (protopathic) sensation.

Effect of Lesion

Bilateral lesion of this tract leads to loss of crude touch sensation and loss of sensations like itching and tickling. Unilateral lesion of this tract causes **loss of crude touch** sensation in opposite side below the level of lesion (because fibers of this tract cross to the opposite side in spinal cord).

■ 2. LATERAL SPINOTHALAMIC TRACT

Lateral spinothalamic tract is formed by the fibers from second order neurons of the pathway for the sensations of **pain** and **temperature** (Fig. 143.4).

Situation

Lateral spinothalamic tract is situated in the **lateral column** towards medial side, i.e. near the gray matter.

Origin

Fibers of lateral spinothalamic tract take origin from two sources:

i. Marginal nucleus
ii. Substantia gelatinosa of Rolando.

Course

Lateral spinothalamic tract has **crossed fibers.** Axons from **marginal nucleus** and **substantia gelatinosa** of **Rolando** cross to the opposite side and reach the lateral column of same segment. Few fibers may ascend one or two segments, then cross to the opposite side and then ascend in the lateral column.

All the fibers pass through medulla, pons and mid-brain and reach thalamus along with fibers of anterior spinothalamic tract. Some of the fibers of lateral spino-thalamic tract form collaterals and reach the reticular formation of brainstem.

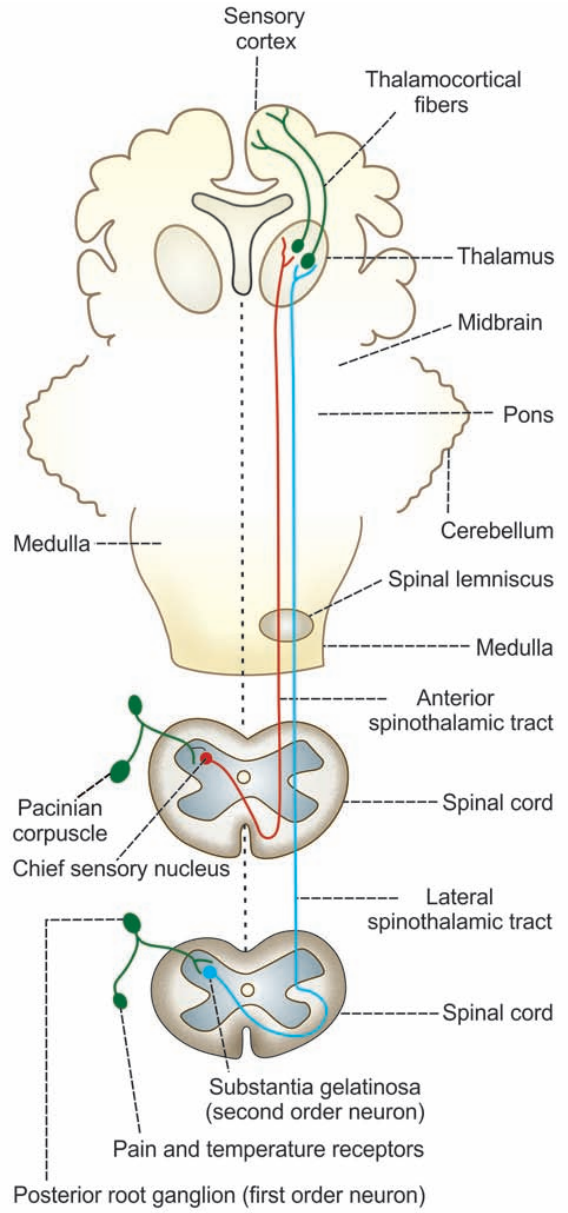

FIGURE 143.4: Spinothalamic tracts and pathways for crude touch, pain and temperature sensations. Anterior spinothalamic tract (red) carries crude touch sensation. Lateral spinothalamic tract (blue) carries pain and temperature sensations.

Fibers of lateral spinothalamic tract form **spinal lemniscus** along with the fibers of anterior spinothalamic tract at the lower part of medulla.

Termination

Fibers of lateral spinothalamic tract terminate in the **ventral posterolateral nucleus** of **thalamus** along with anterior spinothalamic tract fibers. From here, third order neuron fibers run to somesthetic area (sensory cortex) of cerebral cortex.

Function

Fibers of lateral spinothalamic tract carry impulses of **pain** and **temperature** sensations. Fibers arising from this marginal nucleus transmit impulses of fast pain sensation. Fibers arising from substantia gelatinosa of Rolando transmit impulses of slow pain and temperature sensations. Refer Chapter 145 for details of pain fibers.

Effect of Lesion

Bilateral lesion of this tract leads to total loss of pain and temperature sensations on both sides below the level of lesion. Unilateral lesion or sectioning of the lateral spinothalamic tract causes loss of pain **(analgesia)** and temperature **(thermoanesthesia)** below the level of lesion in the opposite side.

■ 3. VENTRAL SPINOCEREBELLAR TRACT

Ventral spinocerebellar tract is also known as **Gower tract, indirect spinocerebellar tract** or **anterior spinocerebellar tract.** It is constituted by the fibers of second order neurons of the pathway for **subconscious kinesthetic sensation** (Fig. 143.5).

Situation

This tract is situated in **lateral white column** of the spinal cord along the lateral periphery.

Origin

Fibers of this tract arise from the **marginal nucleus** in posterior gray horn. Neurons of marginal nucleus form the second order neurons. Fibers from these neurons make their first appearance in **lower lumbar segments** of spinal cord.

First order neurons are in the posterior root ganglia and receive the impulses of proprioception from the proprioceptors in muscle, tendon and joints. Fibers from neurons of posterior root ganglia reach the marginal cells through posterior nerve root.

Course

Ventral spinocerebellar tract contains both **crossed** and **uncrossed fibers.** Majority of the fibers from the marginal nucleus cross the midline and ascend in lateral white column of opposite side. Some fibers ascend in the lateral white column of the same side also. These nerve fibers ascend through other spinal segments, medulla, pons and midbrain.

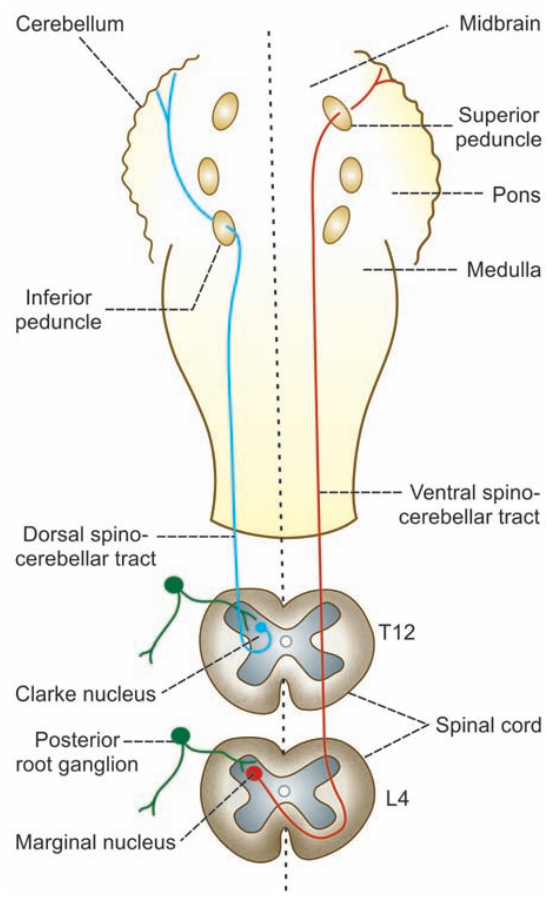

FIGURE 143.5: Spinocerebellar tracts and pathway for subconscious kinesthetic sensation

Finally, the fibers reach the cerebellum through the superior cerebellar peduncle.

Termination

These fibers terminate in the cortex of anterior lobe of **cerebellum.**

Function

Ventral spinocerebellar tract carries the impulses of **subconscious kinesthetic sensation** (proprioceptive impulses from muscles, tendons and joints). Impulses of subconscious kinesthetic sensation are also called **non-sensory impulses.**

Effect of Lesion

Lesion of this tract leads to loss of subconscious kinesthetic sensation in the opposite side.

■ 4. DORSAL SPINOCEREBELLAR TRACT

Dorsal spinocerebellar tract is otherwise called **Flechsig tract, direct spinocerebellar tract** or **posterior spinocerebellar tract.** Like the ventral spinocerebellar tract, this tract is also constituted by the second order neuron fibers of the pathway for subconscious kinesthetic sensation. The first order neurons are in the posterior nerve root ganglia. But, the fibers of this tract are uncrossed (Fig. 143.5).

Situation

Dorsal spinocerebellar tract is situated in the **lateral column** along the posterolateral periphery of spinal cord. It is situated posterior to ventral cerebellar tract and anterior to the entry of posterior nerve root.

Origin

Fibers of this tract originate from the **dorsal nucleus of Clarke** situated in the posterior gray matter of the spinal cord. First appearance of the fibers is in **upper lumbar segments.** From lower lumbar and sacral segments, the impulses are carried upwards by dorsal nerve roots to upper lumbar segments.

Course

Flechsig tract is formed by **uncrossed fibers.** Axons from neurons in dorsal nucleus of Clarke (second order neurons) reach lateral column of same side. Then, these fibers ascend through other spinal segments and reach medulla oblongata. From here, the fibers reach cerebellum through inferior cerebellar peduncle.

Termination

Fibers of this tract end in the cortex of anterior lobe of **cerebellum** along with ventral spinocerebellar tract fibers.

Function

Along with ventral spinocerebellar tract, the dorsal spinocerebellar tract carries the impulses of **subconscious kinesthetic sensation,** which are known as **non-sensory impulses.**

Effect of Lesion

Unilateral loss of the subconscious kinesthetic sensation occurs in lesion of this tract on the same side, as this tract has uncrossed fibers.

■ 5. SPINOTECTAL TRACT

Spinotectal tract is considered as a component of anterior spinothalamic tract. It is constituted by the fibers of second order neurons.

Situation

Spinotectal tract occupies the lateral side of **lateral white column,** anterior to lateral spinothalamic tract. It is bound anteriorly by anterior nerve root.

Origin

Fibers of this tract originate from the **chief sensory nucleus** (like anterior spinothalamic tract). First appearance of the fibers is in upper lumbar segments. This tract is very prominent in the cervical segments.

Course

Spinotectal tract contains **crossed fibers.** After taking origin, the fibers cross to opposite side through anterior white commissure to the lateral column. Then, these fibers ascend to the midbrain along with anterior spinothalamic tract.

Termination

Fibers of spinotectal tract end in the **superior colliculus** of tectum in midbrain.

Function

Spinotectal tract is concerned with **spinovisual reflex.**

■ 6. FASCICULUS DORSOLATERALIS

Fasciculus dorsolateralis is otherwise called **tract of Lissauer.** It is considered as a component of lateral spinothalamic tract. And, it is constituted by the fibers of first order neurons.

Situation

Lissauer tract is situated in the **lateral white column** between the periphery of spinal cord and tip of posterior gray horn.

Origin

Lissauer tract is formed by fibers arising from the **cells of posterior root ganglia** and enters the spinal cord through lateral division of posterior nerve root.

Course

Lissauer tract contains **uncrossed fibers.** After entering spinal cord, the fibers pass upwards or downwards for few segments on the same side and synapse with cells of substantia gelatinosa of Rolando. Axons from these cells (second order neurons) join the lateral spinothalamic tract.

Function

Fibers of the dorsolateral fasciculus carry impulses of **pain** and **thermal sensations.**

■ 7. SPINORETICULAR TRACT

Spinoreticular tract is formed by the fibers of second order neurons.

Situation

Spinoreticular tract is situated in **anterolateral white** column.

Origin

Fibers of this tract arise from **intermediolateral nucleus.**

Course

Spinoreticular tract consists of **crossed** and **uncrossed** fibers. After taking origin, some of the fibers cross the midline and then ascend upwards. Remaining fibers ascend up in the same side without crossing.

Termination

All the fibers terminate in the reticular formation of brainstem by three ways:

i. Some fibers terminate in **nucleus reticularis gigantocellularis** and **lateral reticular nucleus** of medulla in the same side. Some fibers terminate in the nuclei present in the opposite side.
ii. Some fibers terminate in **nucleus reticularis pontis caudalis** of the pons in the same side or opposite side
iii. Very few fibers terminate in midbrain.

Function

Fibers of the spinoreticular tract are the components of ascending reticular activating system and are concerned with consciousness and awareness.

■ 8. SPINO-OLIVARY TRACT

Spino-olivary tract is situated in anterolateral part of white column. Origin of the fibers of this tract is not specific. However, the fibers terminate in olivary nucleus of medulla oblongata. From here, the neurons project into cerebellum. This tract is concerned with **proprioception.**

■ 9. SPINOVESTIBULAR TRACT

Spinovestibular tract is situated in the **lateral white** column of the spinal cord. Fibers of this tract arise from

all the segments of spinal cord and terminate on the **lateral vestibular nucleus.** This tract is also concerned with **proprioception.**

■ 10. FASCICULUS GRACILIS (TRACT OF GOLL) AND

■ 11. FASCICULUS CUNEATUS (TRACT OF BURDACH)

Fasciculus gracilis and fasciculus cuneatus are together called **ascending posterior column tracts.** These tracts are formed by the fibers from posterior root ganglia. Thus, both the tracts are constituted by the fibers of **first order neurons** of sensory pathway (Fig. 143.6).

Situation

Tracts of Goll and Burdach are situated in **posterior white column** of spinal cord hence the name posterior column tracts. In the cervical and upper thoracic segments of spinal cord, the posterior white column is divided by posterior intermediate septum into medial fasciculus gracilis and lateral fasciculus cuneatus.

Thus, the fasciculus gracilis is situated medially in between posterior median sulcus and posterior median septum on one side and posterior intermediate sulcus and posterior intermediate septum on the other side. Fasciculus cuneatus is situated laterally. It is bound medially by posterior intermediate septum and sulcus and laterally by posterior gray horn, tract of Lissauer and posterior nerve root.

Origin

Fibers of these two tracts are the axons of **first order neurons.** Cell body of these neurons is in the **posterior root ganglia** and their fibers form the medial division (bundle) of posterior nerve root.

Course

After entering spinal cord, the fibers ascend through the **posterior white column.** These fibers do not synapse in the spinal cord. Some fibers of medial division of posterior nerve root descend through posterior white column in the form of **fasciculus interfascicularis** or **comma tract of Schultze.**

Fasciculus gracilis contains the fibers from **lower extremities** and **lower parts of the body,** i.e. from sacral, lumbar and lower thoracic ganglia of posterior nerve root. Fasciculus cuneatus contains fibers from **upper part of the body,** i.e. from upper thoracic and cervical ganglia of posterior nerve root.

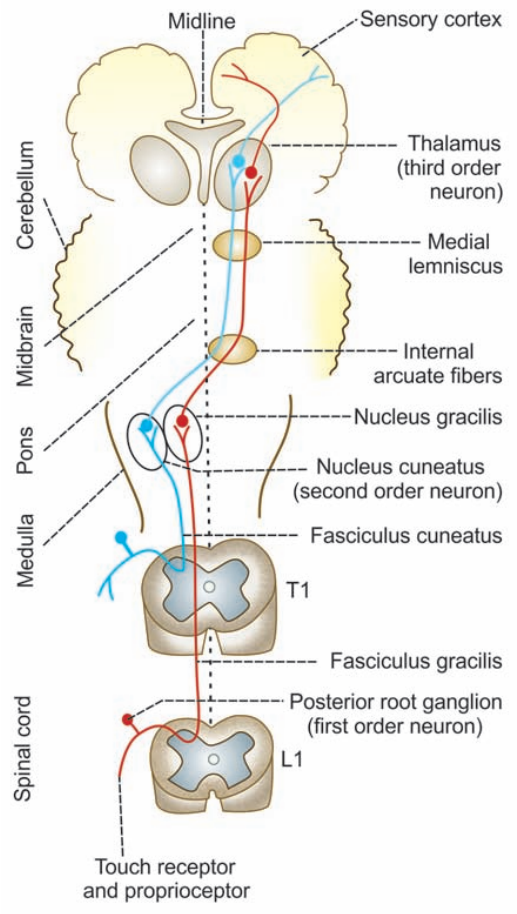

FIGURE 143.6: Ascending tracts in posterior white column of spinal cord and pathway for – 1. Fine touch sensation, 2. Tactile localization, 3. Tactile discrimination, 4. Vibratory sensation, 5. Conscious kinesthetic sensation, 6. Stereognosis.

Termination

Tracts of Goll and Burdach terminate in the medulla oblongata. Fibers of fasciculus gracilis terminate in the **nucleus gracilis** and the fibers of fasciculus cuneatus terminate in the **nucleus cuneatus.** Neurons of these medullary nuclei form the second order neurons.

Axons of second order neurons form the **internal arcuate fibers.** Internal arcuate fibers from both sides cross the midline forming **sensory decussation** and then ascend through pons and midbrain as **medial lemniscus.** Fibers of medial lemniscus terminate in **ventral posterolateral nucleus of thalamus.** From here, fibers of the third order neurons relay to **sensory area of cerebral cortex.**

Functions

Tracts of the posterior white column convey impulses of following sensations:

i. **Fine** (epicritic) **tactile sensation**
ii. **Tactile localization** (ability to locate the area of skin where the tactile stimulus is applied with closed eyes)
iii. **Tactile discrimination** or two point discrimination (ability to recognize the two stimuli applied over the skin simultaneously with closed eyes)
iv. **Sensation of vibration** (ability to perceive the vibrations from a vibrating tuning fork placed over bony prominence conducted to deep tissues through skin). It is the synthetic sense (Chapter 144) produced by combination of touch and pressure sensations.
v. **Conscious kinesthetic sensation** (sensation or awareness of various muscular activities in different parts of the body)
vi. **Stereognosis** (ability to recognize the known objects by touch with closed eyes). It is also a synthetic sense produced by combination of touch and pressure sensations.

Effect of Lesion

Lesion of nerve fibers in tracts of Goll and Burdach or lesion in the posterior white column leads to the following symptoms on the same side below the lesion:

i. Loss of fine tactile sensation; however, crude touch sensation is normal
ii. Loss of tactile localization
iii. Loss of two point discrimination
iv. Loss of sensation of vibration
v. **Astereognosis** (inability to recognize known objects by touch while closing the eyes)
vi. Lack of ability to differentiate the weight of different objects
vii. Loss of proprioception (inability to appreciate the position and movement of different parts of the body)
viii. **Sensory ataxia** or posterior column ataxia (condition characterized by uncoordinated, slow and clumsy voluntary movements because of the loss of proprioception).

■ 12. COMMA TRACT OF SCHULTZE

Comma tract of schultze is also called fasciculus interfascicularis. It is situated in between tracts of Goll and Burdach. This tract is formed by the short descending fibers, arising from the medial division of posterior nerve root. These fibers are also considered as the descending branches of the tracts of Goll and Burdach. Function of this tract is to establish intersegmental communications and to form short reflex arc.

■ DESCENDING TRACTS OF SPINAL CORD

Descending tracts of the spinal cord are formed by motor nerve fibers arising from brain and descend into the spinal cord. These tracts carry motor impulses from brain to spinal cord.

Descending tracts of spinal cord are of two types:

A. Pyramidal tracts
B. Extrapyramidal tracts.

Descending tracts are listed in Table 143.3 and their features given in Table 143.4.

■ PYRAMIDAL TRACTS

Pyramidal tracts were the first tracts to be found in man. Pyramidal tracts of spinal cord are the descending tracts concerned with voluntary motor activities of the body. These tracts are otherwise known as **corticospinal tracts.** There are two corticospinal tracts, the anterior corticospinal tract and lateral corticospinal tract. While running from cerebral cortex towards spinal cord, the fibers of these two tracts give the appearance of a **pyramid** on the upper part of anterior surface of medulla oblongata hence the name pyramidal tracts (Fig. 143.7).

Nerve Fibers

All the fibers of the pyramidal tracts are present since birth. However, myelination of these fibers is completed in about 2 years after birth. The pyramidal tracts on each side have more than a million fibers. About 70% of the fibers are large myelinated fibers having a diameter of 4 to 22 micron.

TABLE 143.3: List of descending tracts of spinal cord

Type	Tract
Pyramidal tracts	1. Anterior corticospinal tract 2. Lateral corticospinal tract
Extrapyramidal tracts	1. Medial longitudinal fasciculus 2. Anterior vestibulospinal tract 3. Lateral vestibulospinal tract 4. Reticulospinal tract 5. Tectospinal tract 6. Rubrospinal tract 7. Olivospinal tract

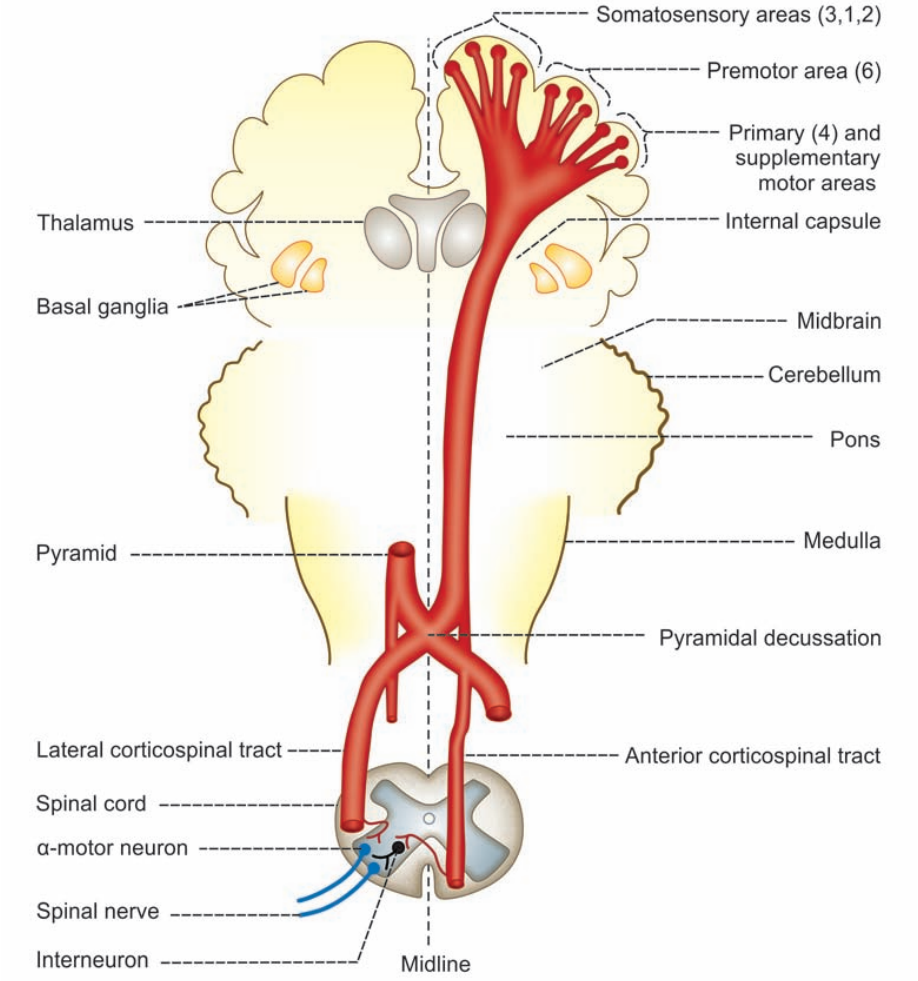

FIGURE 143.7: Pyramidal tracts

Large fibers of pyramidal tracts have the tendency to disappear at old age. Since these tracts are concerned with control of voluntary movements, the disappearance of the fibers of pyramidal tracts causes automatic **shivering** movements in old age.

Fibers of pyramidal tracts are the axons of upper motor neurons.

Origin

Fibers of pyramidal tracts arise from following cells or areas of cerebral cortex:

1. **Giant cells** or **Betz cells** or pyramidal cells in precentral gyrus of the motor cortex. These cells are situated in area 4 (primary motor area) of frontal lobe.
2. Other areas of motor cortex namely, premotor area (area 6) and supplementary motor areas
3. Other parts of frontal lobe
4. Somatosensory areas of parietal lobe.

It is believed that 30% of pyramidal fibers arise from primary motor area (area 4) and supplementary motor areas, another 30% from premotor area (area 6) and the remaining 40% of fibers arise from somatosensory areas. All the above fibers form fibers of upper motor neurons of motor pathway.

Course

Corona radiata

After taking origin, the nerve fibers run downwards in a diffused manner through white matter of cerebral hemisphere and converge in the form of a fan-like structure along with ascending fibers, which project from thalamus to cerebral cortex. This fan-like structure

TABLE 143.4: Descending tracts of spinal cord

	Tract	Situation	Origin	Course	Function
Pyramidal Tracts	1. Anterior corticospinal tract	Anterior white column	Betz cells and other cells of motor area	Uncrossed fibers	i. Control of voluntary movements ii. Form upper motor neurons
	2. Lateral corticospinal tract	Lateral white column	Betz cells and other cells of motor area	Crossed fibers	
Extrapyramidal tracts	1. Medial longitudinal fasciculus	Anterior white column	Vestibular nucleus Reticular formation Superior colliculus and cells of Cajal	Uncrossed fibers Extend up to uppercervical segments	i. Coordination of reflex ocular movements ii. Integration of movements of eyes and neck
	2. Anterior vestibulospinal tract	Anterior white column	Medial vestibular nucleus	Uncrossed fibers Extend up to upper thoracic segments	i. Maintenance of muscle tone and posture ii. Maintenance of position of head and body during acceleration
	3. Lateral vestibulospinal tract	Lateral white column	Lateral vestibular nucleus	Mostly uncrossed Extend to all segments	
	4. Reticulospinal tract	Lateral white fasciculus	Reticular formation of pons and medulla	Mostly uncrossed Extend up to thoracic segments	i. Coordination of voluntary and reflex movements ii. Control of muscle tone iii.Control of respiration and diameter of blood vessels
	5. Tectospinal tract	Anterior white column	Superior colliculus	Crossed fibers Extend up to lower cervical segments	Control of movement of head in response to visual and auditory impulses
	6. Rubrospinal tract	Lateral white column	Red nucleus	Crossed fibers Extend up to thoracic segments	Facilitatory influence on flexor muscle tone
	7. Olivospinal tract	Lateral white column	Inferior olivary nucleus	Mostly crossed Extent – not clear	Control of movements due to proprioception

Termination – fibers of all the tracts terminate in motor neurons situated in the anterior gray horn of spinal cord.

is called corona radiata. Thus, corona radiata contains both ascending fibers from thalamus and descending fibers from cerebral cortex.

Internal capsule

While passing down towards the brainstem the corona radiata converges in the form of internal capsule. It is situated in between thalamus and caudate nucleus on the medial side and lenticular nucleus on the lateral side (Chapter 148).

In pons

The fibers descend down through internal capsule, midbrain and pons. While descending through pons, the fibers are divided into different bundles by the nuclei of pons. At lower border of pons, the fibers are grouped once again into a compact bundle and then descend down into medulla oblongata.

In medulla

This compact bundle of corticospinal fibers gives the appearance of a **pyramid** in the anterior surface of upper part of medulla. So, the corticospinal tracts are called the pyramidal tracts.

At the lower border of medulla, pyramidal tract on each side is divided into two bundles of unequal sizes. About 80% of fibers from each side cross to the opposite side. While crossing the midline, the fibers of both sides form the **pyramidal decussation.**

In spinal cord

Fibers which cross the midline and form pyramidal decussation descend through posterior part of lateral white column of spinal cord. This bundle of crossed fibers is called the **crossed pyramidal tract** or **lateral corticospinal tract** or **indirect corticospinal tract.**

Remaining 20% of fibers do not cross to the opposite side but descend down through the anterior white column of the spinal cord. This bundle of uncrossed fibers is called the **uncrossed pyramidal tract** or **anterior corticospinal tract** or **direct corticospinal tract.** This tract is well marked in cervical region. Since, the fibers of this tract terminate in different segments of spinal cord, this tract usually gets thinner while descending through the successive segments of spinal cord. Fibers of this tract are absent mostly below the mid thoracic level. Before termination, majority of the fibers of this anterior corticospinal tract cross to the opposite side at different levels of spinal cord.

Termination

All the fibers of pyramidal tracts, both crossed and uncrossed fibers, terminate in the motor neurons of anterior gray horn either directly or through internuncial neurons. Pyramidal tract fibers terminate on both **α-motor neurons** and **β-motor neurons.** Axons of the motor neurons leave the spinal cord as spinal nerves through anterior nerve roots and supply the skeletal muscles.

Neurons giving origin to the fibers of pyramidal tract are called the **upper motor neurons.** Anterior motor neurons in the spinal cord are called the **lower motor neurons.**

Function

Pyramidal tracts are concerned with **voluntary movements** of the body. Fibers of the pyramidal tracts transmit motor impulses from motor area of cerebral cortex to the anterior motor neurons of the spinal cord. These two tracts are responsible for fine, skilled movements.

Effects of lesion

Lesion in the neurons of motor cortex and the fibers of pyramidal tracts is called the **upper motor neuron lesion.** In human beings, pure pyramidal tract lesions do not occur. Lesion of pyramidal fibers occurs most commonly in **stroke** (cardiovascular accident) due to hemorrhage and thrombosis. During such lesions, many extrapyramidal fibers are also damaged along with pyramidal fibers. Because of this reason, neurologists often consider the lesion as upper motor neuron lesion and not as pyramidal tract lesion.

Following are the effects of lesion:

1. *Voluntary movements*

Voluntary movements of the body are very much affected. Initially, there is loss of voluntary movements in the extremities. Later, it involves the other parts of the body like hip and shoulder.

2. *Muscle tone*

Muscle tone is increased leading to **spasticity.** Muscles are also paralyzed. This type of paralysis of muscles is called the **spastic paralysis.** The spasticity is due to the failure of inhibitory impulses from upper motor neurons, particularly the neurons of extrapyramidal system to reach the γ-motor neurons in spinal cord.

However, hypotonia occurs in pure pyramidal tract lesion, which is very rare. In monkeys, sectioning of pyramidal tract fibers alone results in **hypotonia.**

3. *Reflexes*

All the superficial reflexes are lost and the deep reflexes are exaggerated. Abnormal plantar reflex called **Babinski sign** is present (Babinski sign positive).

More details of upper motor neuron lesion are given in the next chapter.

Effects of Lesion at Different Levels

Cerebral cortex

Lesion of pyramidal tract fibers in cerebral cortex causes **hypertonia, spasticity** and contralateral monoplegia (paralysis of one limb) or contralateral **hemiplegia** (paralysis of one side of the body).

Internal capsule

Lesion of pyramidal tract fibers at posterior limb of internal capsule results in contralateral **hemiplegia.**

Brainstem

Lesion at brainstem involves not only pyramidal tract fibers but also other structures such as VI and VII cranial nerve nuclei. So the lesion results in contralateral **hemiparesis** (weakness of muscles in one side of the body) along with VI and VII cranial nerve palsies.

Spinal cord

Unilateral lesion of lateral corticospinal fibers at upper cervical segment causes ipsilateral **hemiplegia** and bilateral lesion causes **quadriplegia** (paralysis of all four limbs) and paralysis of respiratory muscles.

Bilateral lesion of these fibers in thoracic and lumbar segments results in **paraplegia** (paralysis of both lower limbs) without paralysis of respiratory muscles.

■ EXTRAPYRAMIDAL TRACTS

Descending tracts of spinal cord other than pyramidal tracts are called extrapyramidal tracts. Extrapyramidal tracts are listed in Table 143.3.

■ 1. MEDIAL LONGITUDINAL FASCICULUS

Situation

Medial longitudinal fasciculus descends through posterior part of **anterior white column** of the spinal cord.

Origin

Actually, this tract is the extension of medial longitudinal fasciculus of brainstem. Fibers of this tract take origin from four different areas in brainstem:

i. Vestibular nuclei
ii. Reticular formation
iii. Superior colliculus
iv. Interstitial cells of Cajal.

Course

After entering the spinal cord from the brainstem, the fibers of medial longitudinal fasciculus descend through posterior part of anterior white column of the same side. In the spinal cord, this tract is well defined only in upper cervical segments. Below this level, the fibers run along with the fibers of anterior vestibulospinal tract.

Extent

Fibers of this tract extend up to the **upper cervical segments** of spinal cord.

Termination

Fibers of this tract terminate in anterior motor neurons of the spinal cord along with fibers of anterior vestibulospinal tract either directly or through internuncial neurons.

Function

Medial longitudinal fasciculus helps in the coordination of **reflex ocular movements** and the integration of ocular and neck movements.

Effects of Lesion

Reflex ocular movements and reflex neck movements are affected in the lesion of this tract.

■ 2. ANTERIOR VESTIBULOSPINAL TRACT

Situation

Anterior vestibulospinal tract is situated in the **anterior white column,** along the periphery of spinal cord lateral to tectospinal tract.

Origin

Fibers of this tract arise from medial vestibular nucleus in medulla oblongata. In fact, anterior vestibulospinal tract is the extension of medial longitudinal fasciculus. Most of the fibers are uncrossed.

Extent

Fibers run up to **thoracic segments** of spinal cord.

Course

Fibers of this tract run down from medulla into the anterior column of spinal cord along the periphery. All the fibers are uncrossed.

Termination

Along with fibers of lateral vestibulospinal tract, the fibers of this tract terminate in anterior motor neurons directly or through internuncial neurons.

Function

Function of this tract is explained along with the function of lateral vestibulospinal tract.

■ 3. LATERAL VESTIBULOSPINAL TRACT

Situation

Lateral vestibulospinal tract occupies the anterior part of **lateral white column** of spinal cord.

Origin

Fibers of this tract take origin from the **lateral vestibular nucleus** in medulla. This nucleus is also called Deiter nucleus.

Extent

Fibers of this tract are present **throughout the spinal cord.**

Course

From Deiter nucleus, most of the fibers descend directly through lateral column. Very few fibers cross to the opposite side before descending.

Termination

Fibers of this tract terminate in the anterior motor neuron, either directly or via internuncial neurons.

Functions

Vestibular nuclei receive impulses concerned with muscle tone and posture from vestibular apparatus and cerebellum. Vestibular nuclei in turn convey the impulses to different parts of the body through the anterior and lateral vestibulospinal tracts.

Vestibulospinal tracts are concerned with adjustment of **position of head and body** during angular and linear acceleration.

Effect of Lesion

Adjustment of head and body becomes difficult during acceleration when the vestibulospinal tracts are affected by lesion.

■ 4. RETICULOSPINAL TRACT

Situation

Reticulospinal tract is situated in the **anterior white column,** posterior to anterior vestibulospinal tract.

Origin

Fibers of this tract arise from the **reticular formation** of pons and medulla. Pontine reticular fibers are uncrossed (direct) and descend in medial part of anterior column. Fibers from medullary reticular formation are predominantly uncrossed and only few fibers are crossed. These fibers descend in lateral part of anterior column and to some extend in the anterior part of lateral column.

Extent

Fibers of reticulospinal tract extend up to **thoracic segments.**

Termination

Fibers of reticulospinal tract terminate in gamma motor neurons of anterior gray horn through the internuncial neuron.

Functions

Reticulospinal tract is concerned with control of **movements** and maintenance of **muscle tone,** respiration and diameter of blood vessels. Pontine and medullary fibers have opposite effects on these functions, which are given in Table 143.5.

TABLE 143.5: Functions of pontine and medullary reticulospinal fibers

Function	Pontine reticular fibers	Medullary reticular fibers
Control of voluntary and reflex movements	Facilitation	Inhibition
Control of muscle tone through gamma motor neurons	Facilitation	Inhibition
On respiration	Favor expiration	Favor inspiration
On blood vessels	Cause vasoconstriction	Cause vasodilatation

Effect of Lesion

Lesion of reticulospinal tract causes disturbances in respiration, blood pressure, movements of body and muscle tone.

■ 5. TECTOSPINAL TRACT

Situation

Tectospinal tract is situated in the **anterior white column** of spinal cord.

Origin

Nerve fibers of this tract arise from **superior colliculus** of midbrain.

Extent

Tectospinal tract extends only up to **lower cervical segments.**

Course

After taking origin from superior colliculus, the fibers cross the midline in dorsal tegmental decussation and descend in anterior column.

Termination

Fibers of tectospinal tract terminate in the anterior motor neurons of spinal cord, directly or via internuncial neurons.

Function

Tectospinal tract is responsible for the **movement of head** in response to visual and auditory stimuli.

■ 6. RUBROSPINAL TRACT

Situation

Rubrospinal tract is situated in the **lateral white column** of spinal cord.

Origin

Fibers of this tract arise from large cells (nucleus magnocellularis) of **red nucleus** in midbrain.

Extent

Nerve fibers of this tract appear in the spinal cord only **up to thoracic segments.**

Course

After arising from the red nucleus, the fibers cross the midline in ventral tegmental decussation and descend into spinal cord through the reticular formation of pons and medulla.

Termination

Fibers of rubrospinal tract end in the anterior motor neurons of the spinal cord via internuncial neurons.

Function

Rubrospinal tract exhibits facilitatory influence upon **flexor muscle tone.**

■ 7. OLIVOSPINAL TRACT

Situation

Olivospinal tract is present in **lateral white column** of spinal cord.

Origin

The nerve fibers of the olivospinal tract take origin from the **inferior olivary nucleus,** which is present in the medulla oblongata.

Termination

Fibers of this tract terminate in the anterior motor neurons of spinal cord.

Function

Functions of the olivospinal tract are not known clearly. It is believed that this tract is involved in **reflex movements** arising from the proprioceptors.

■ APPLIED PHYSIOLOGY

Spinal cord injury leads to either temporary or permanent dysfunction. Dysfunction of spinal cord occurs because of:

1. Direct injury due to bullet firing or accidents (on road, in working place, during communal violence, etc.)
2. Compression by bone fragments, hematoma or disk material
3. Ischemia due to rupture of spinal arteries.

During mechanical injury, spinal cord may be cut into two or one lateral half of the spinal cord may be damaged or diffused crushing of several segments of spinal cord may also occur.

Accordingly, dysfunction of spinal cord is classified into four types:

A. Complete transection
B. Incomplete transection
C. Hemisection
D. Diseases of spinal cord.

■ COMPLETE TRANSECTION OF SPINAL CORD

Complete transection of spinal cord occurs due to:

1. Bullet injury, which causes dislocation of spinal cord
2. Accidents, which cause dislocation of spinal cord or occlusion of blood vessels.

Complete transection causes immediate **loss of sensation** and **voluntary movement** below the level of lesion. In quick transection of spinal cord, the patient feels himself cut into two. For a while, his mind remains clear but he feels as if his lower part of the body below the injury does not exist. It is because his higher centers remain unaffected but the spinal centers below the level of injury loose the function.

Then the effects (symptoms) of complete transection of spinal cord start appearing. Effects occur in three stages:

1. Stage of spinal shock
2. Stage of reflex activity
3. Stage of reflex failure.

1. *Stage of Spinal Shock*

Stage of spinal shock is the first stage of effects that occurs immediately after injury. It is also called **stage of flaccidity.** Following are the signs and symptoms that develop during this stage:

i. *Paralysis of limbs*

Paralysis occurs in two limbs or in all four limbs. Paralysis of limbs depends upon the level of Injury:

a. Injury at the cervical region of the spinal cord leads to the paralysis of all the four limbs. Paralysis of all the four limbs is called **quadriplegia** or **tetraplegia**
b. Injury at the thoracic, lumbar or sacral segments including cauda equina and conus medullaris causes paralysis of lower limbs. Paralysis of lower limbs is called **paraplegia.**

ii. *Flaccid paralysis*

Paralyzed muscles become flaccid, i.e. loose stiffness because of loss of tone. This type of paralysis is called **flaccid paralysis.**

iii. *Loss of reflexes*

All the reflexes are lost because of the injury to anterior and posterior nerve roots.

iv. *Loss of sensations*

All the sensations are lost because of the injury to posterior nerve roots and sensory neurons in the posterior gray horn.

v. *Effect on visceral organs*

Some of the visceral organs are also affected; especially, urinary bladder and rectum are paralyzed.

vi. *Heart rate*

Heart rate is decreased and pulse becomes weak and thready.

vii. *Venous return*

Venous return is very much decreased. Venous return depends upon the muscle tone during resting condition. During activity it depends upon contraction of skeletal muscle (muscle pump, refer to Chapter 98). But, in complete transection of spinal cord, muscle tone is lost and flaccid paralysis occurs. This leads to decrease in venous return.

In addition, the limbs are immobile and smooth muscles of blood vessels loose the tone. So, the blood gets accumulated in blood vessels of limbs, particularly in lower limbs. And, the lower limbs become **cold and blue.**

viii. *Effect on blood pressure*

Effect on blood pressure depends upon the level of injury:

a. *Lesion anywhere below L2 segment*
   Blood pressure is not affected much because the sympathetic vasoconstrictor fibers leave the spinal cord between T1 and L2 segments.
b. *Lesion at or above T1 segment*
   All the sympathetic vasoconstrictor fibers leaving the spinal cord from T1 and L2 segments are transected and are completely cut off from higher medullary cardiovascular centers, which regulate the blood pressure. So the blood pressure falls drastically. Mean arterial pressure falls below 40 mm Hg.

Severity of complete transection depends upon the level of lesion. Complete transection at the level of cervical region can be very fatal. Because, the diaphragm and other respiratory muscles are cut off from

respiratory centers. It causes paralysis of respiratory muscles leading to sudden arrest of breathing.

The **crushing injury** at sacral segments of spinal cord results in atonic bladder and loss of micturition reflex (Chapter 57).

In human beings, the stage of spinal shock lasts for about 3 weeks. In animals the duration of spinal shock varies in different species. In amphibians like frog, it lasts only for few minutes. In mammals like dogs and cats, it lasts for few hours. In monkeys, it lasts for few days.

2. *Stage of Reflex Activity*

Stage of reflex activity is also called **stage of recovery.** After 3 weeks period, depending largely upon the general health of the patient, the reflex activity begins to return to the isolated segments of spinal cord below the level of lesion.

Developments taking place in this stage

i. First, the functional activities return to smooth muscles
ii. Next, the sympathetic tone to blood vessels returns. As the neurons in gray horn act independently of vasomotor center, the tone in blood vessels is restored and the blood pressure is also restored to its normal level.
iii. Lastly, after another 3 months, the tone in skeletal muscle returns. Tone returns to flexor muscles first. So, the flexor muscles of lower limb become less flabby and offer some resistance to the toes. Though the tonicity is returned, it is not complete even in flexor muscles. So, the muscles remain hypotonic.

Limbs in this condition tend to adopt a position of slight flexion and the paralysis is therefore called the **paraplegia in flexion.** Limbs cannot support weight of the body.

iv. After few weeks, when tone returns to more muscles, reflex movements can occur. Flexor reflexes appear first. To elicit the flexor reflex, a painful stimulus is required. First reflex, which usually appears, is the **Babinski reflex.**
v. After a variable period of 1 to 5 weeks of reappearance of flexor reflexes, the extensor reflexes return. Initially, knee jerk returns and then the ankle jerk.
vi. In some cases, a widespread reaction can be elicited by scratching the skin over the lower limbs or the anterior abdominal wall, depending upon the level of lesion. This reaction constitutes the spasm in flexor muscles of both the lower limbs, evacuation of urinary bladder and profuse sweating. This is known as the **mass reflex.**

3. *Stage of Reflex Failure*

Though the reflex movements return, muscles below the level of injury have less power and less resistance. Usually, general condition of the patient starts deteriorating. General infection or **toxemia** becomes common. Due to this, the failure of reflex function develops. The reflexes become more difficult to elicit. The threshold for stimulus increases. Mass reflex is abolished and the muscles become extremely **flaccid** and undergo **wasting.**

■ INCOMPLETE TRANSECTION OF SPINAL CORD

If spinal cord is gravely injured, but does not suffer complete division, the condition is called as incomplete transection.

Symptoms of Incomplete Transection

After incomplete transection of the spinal cord, all the three stages of complete transection occur.

1. Stage of spinal shock
2. Stage of reflex activity
3. Stage of reflex failure.

1. *Stage of Spinal Shock*

Features are similar to those of complete transection.

2. *Stage of Reflex Activity*

Features of this stage:

i. Tone returns to extensor muscles first and not to the flexor muscles. This is because, in incomplete transection, some of the descending fibers in lateral column of cord, especially vestibulospinal and reticulospinal tracts may escape the injury. So, some connections persist between brainstem and spinal cord. Fibers of vestibulospinal and reticulospinal tracts mainly reinforce the activity of extensor motor neurons.

Because of this, there is extensor hypertonia and so, the lower limbs are extended at hip and knee with toes pointing slightly downwards. This condition is known as **paraplegia in extension.**

ii. Stretch reflex reappears first. Flexor reflexes return later. **Philipson reflex (clasp-knife reflex)** can be elicited.
iii. In the upper limb, some resistance is offered when the arm is flexed at elbow joint passively. That is, the arm cannot be flexed. This resistance is offered because of the stretch reflex developed in the triceps muscle. However, if forearm is flexed forcefully, the resistance to flexion is abolished

suddenly, leading to quick flexion of arm. This is called the **Philipson reflex** or **clasp-knife reflex.**

iv. Mass reflex, which is produced in complete transection, does not occur in incomplete transection of spinal cord.

3. *Stage of Reflex Failure*

Features are similar to those of complete transection.

■ HEMISECTION OF SPINAL CORD – BROWN-SÉQUARD SYNDROME

Lesion involving one lateral half of the spinal cord is called hemisection (Fig. 143.8). It can occur due to injury during accidents. It can also be produced experimentally in animals.

Symptoms of Hemisection of Spinal Cord

Signs and symptoms, which occur after hemisection of the spinal cord, constitute Brown-Séquard syndrome.

If the hemisection is due to injury, spinal shock occurs immediately. Muscles loose the tone and become flaccid. The reflexes are abolished. In case the patient survives, this stage gradually passes off and certain signs and symptoms develop. Effects are seen below the level of lesion and at the level of lesion. Effects in these areas differ on the same side and opposite side. There are changes in sensory and motor functions.

■ EFFECTS OF HEMISECTION OF SPINAL CORD BELOW THE LEVEL OF LESION

On the Same Side

Sensory changes

1. On the same side below the level of lesion, following sensations are lost because these sensations are carried by the **uncrossed fibers** of tracts of Goll and Burdach:
   i. Fine touch
   ii. Tactile localization
   iii. Tactile discrimination
   iv. Sensation of vibration
   v. Conscious kinesthetic sensation
   vi. Stereognosis.
2. Some sensations are not affected because these sensations are carried by **crossed fibers** of spinothalamic tracts. These sensations are:
   i. Crude touch
   ii. Pain
   iii. Temperature.

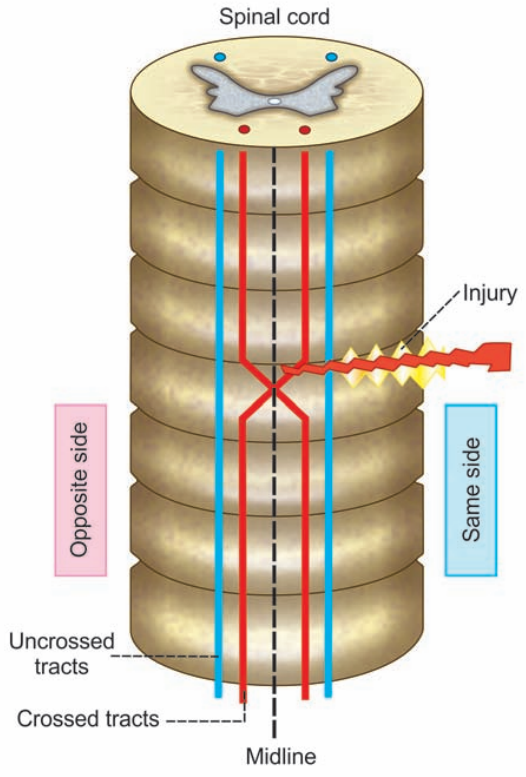

FIGURE 143.8: Hemisection of spinal cord (Brown-Séquard syndrome). Below the level of lesion: same side = loss of sensations carried by uncrossed fibers, opposite side = loss of sensations carried by crossed fibers. At the level of lesion: same side = complete anesthesia, opposite side = loss of sensations carried by crossed fibers.

Motor changes

Motor changes resemble the effects of upper motor neuron lesion (Chapter 144).

1. Muscle tone increases, leading to spastic paralysis
2. Rigidity of limbs occurs
3. Muscle wastage does not occur
4. Superficial reflexes are lost
5. Babinski sign is positive
6. Deep reflexes are exaggerated
7. Fall in blood pressure because of loss of vasomotor tone.

On the Opposite Side

Sensory changes

1. On the opposite side, below the level of lesion, the following sensations are lost completely because, these sensations are carried by **crossed spinothalamic tracts:**

TABLE 143.6: Effects of hemisection (Brown-Séquard syndrome) of spinal cord

Level	Same side		Opposite side	
	Sensory changes	Motor changes	Sensory changes	Motor changes
Below the level of lesion	**Sensations lost** *Sensations carried by uncrossed tracts:* 1. Fine touch 2. Tactile localization 3. Tactile discrimination 4. Vibration sense 5. Conscious kinesthetic sensation 6. Stereognosis **Sensations retained** *Sensations carried by crossed tracts:* 1. Crude touch 2. Pain 3. Temperature	**Upper motor neuron lesion type** 1. Increased tone 2. Spastic paralysis 3. Loss of superficial reflexes 4. Exaggeration of deep reflexes 5. Babinski positive sign 6. Rigidity in the limbs 7. No muscular wastage	**Sensations lost** *Sensations carried by crossed tracts:* 1. Crude touch 2. Pain 3. Temperature **Sensations retained** *Sensations carried by uncrossed tracts:* 1. Fine touch 2. Tactile localization 3. Tactile discrimination 4. Vibration sense 5. Conscious kinesthetic sensation 6. Stereognosis	**No paralysis** *If it occurs:* 1. Very mild 2. Resembles upper motor neuron lesion type
At the level of lesion	**Complete anesthesia**	**Lower motor neuron lesion type** 1. Loss of muscle tone 2. Flaccid paralysis 3. Loss of all reflexes 4. Wastage of muscle 5. Loss of vasomotor tone	**Sensations lost** *Sensations carried by crossed tracts:* 1. Crude touch 2. Pain 3. Temperature **Sensations retained** *Sensations carried by uncrossed tracts:* 1. Fine touch 2. Tactile localization 3. Tactile discrimination 4. Vibration sense 5. Conscious kinesthetic sensation 6. Stereognosis	**No paralysis** *If it occurs:* 1. Very mild 2. Resembles lower motor neuron lesion type

i. Crude touch
ii. Pain
iii. Temperature.

2. Following sensations are not affected because, these sensations are carried by **uncrossed tracts** of Goll and Burdach:
   i. Fine touch
   ii. Tactile localization
   iii. Tactile discrimination
   iv. Sensation of vibration
   v. Conscious kinesthetic sensation
   vi. Stereognosis.

Motor changes

Mostly there may not be any paralysis of muscles. If it occurs, it would be mild as only a few fibers of pyramidal tract are affected. This is because pyramidal fibers cross to the opposite side. Paralysis is of **upper motor neuron lesion** type.

Thus, during hemisection of spinal cord, motor loss is extensive and sensory loss is less below the level of lesion on the same side. On the opposite side, sensory loss is extensive and motor loss is less.

■ EFFECTS OF HEMISECTION OF SPINAL CORD AT THE LEVEL OF LESION

On the Same Side

Sensory changes

On the same side at the level of hemisection, there is complete anesthesia. That is, all the sensations are lost

(Table 143.6). This is because of complete destruction of the posterior nerve root.

Motor changes

Effects of **lower motor neuron lesion** occur because the motor neurons and their fibers leaving the spinal cord are affected.

Motor changes of lower motor neuron lesion are:

1. Muscles loose the tone and become flaccid and paralyzed. This type of paralysis with loss of muscle tone is called flaccid paralysis.
2. All the reflexes are lost
3. Muscles degenerate and undergo wasting due to loss of tone
4. Vasomotor tone is lost.

On the Opposite Side

Sensory changes

1. There is loss of pain, temperature and crude touch sensations because the **crossed spinothalamic tracts** are affected
2. But tracts of Goll and Burdach are not affected. So, the sensations carried by these two tracts are not affected.

Motor changes

No motor change occurs. If it occurs, it is very mild and is similar to the effects of **lower motor neuron lesion** (Chapter 144).

■ DISEASES OF SPINAL CORD

1. *Syringomyelia*

Syringomyelia is spinal cord disorder characterized by the presence of **fluid-filled cavities** in the spinal cord. Gray matter around the central canal is the most affected part. So the sensory disturbances are more pronounced than the motor disturbances.

Cause

Stringomyelia occurs due to the over growth of neuroglial cells in spinal cord accompanied by cavity formation and accumulation of fluid. Initially, a cavity appears in gray matter near the central canal of spinal cord. In later stages, the cavity extends and involves the surrounding white matter to a variable degree.

The disease usually starts in one or two segments. Then, it extends up and down for considerable distances. Lower cervical and upper thoracic regions are affected the most.

Features

Characteristic features of this disease are the loss of pain and temperature sensations and muscular weakness. Severity of the loss of sensations depends upon the extent of disease in spinal cord.

Symptoms of syringomyelia:

1. If disease is only **around central canal,** there is loss of temperature, pain and crude touch sensations only. It is due to lesion of the fibers crossing through the anterior gray commissure. Fine touch sensation is not affected because the fibers of fine touch pathway are in the posterior white column.
2. If lesion is **unilateral,** effect occurs only on the same side
3. If disease extends to **posterior gray horn,** all the sensations are lost. Due to loss of pain and temperature sensations, the affected part is not withdrawn either reflexly or consciously from a painful stimulus. So, the affected persons become prone for injuries. Since, the injury is not perceived it leads to severe damage to the tissues.
4. If **anterior gray horn** is affected, there is flaccid paralysis of muscles. In later stages, both pyramidal and extrapyramidal tracts are also involved, if the disease spreads to white matter. It causes spastic paralysis of limbs, especially in lower limbs, resulting in **spastic paraplegia.** Weakness and **wasting** of small muscle of limbs occur. **Winging of scapula** and **scoliosis** (lateral curvature of spine) develops.

2. *Tabes Dorsalis*

Tabes dorsalis is another disease of the spinal cord. It is a slowly progressive nervous disorder affecting both the motor and sensory functions of spinal cord.

Cause

It occurs due to the degeneration of posterior (sensory) nerve roots. It usually occurs in **syphilis.**

Posterior nerve roots are affected proximal to the posterior root ganglia. Ganglia are not affected. Among the fibers of posterior root, the fibers of lateral division are affected much. Reason for this type of selective degeneration is not known.

Along with lateral fibers of posterior root, the fibers in posterior white column of spinal cord are also affected.

Features

In tabes dorsalis, both sensory and motor functions are affected. Following are the features:

Sensations

1. During the onset of degenerative changes, there is exaggeration of pain sensation
2. Then, there is impairment and loss of all sensations
3. Loss of sensations, particularly pain sensation leads to deformities of joint. There is no proper support and movements at the joints become uncontrolled. It is called **Charcot joint.**
4. Joints enlarge due to inflammation by the development of osteoarthritis.

Reflexes

Both superficial and deep reflexes are lost in tabes dorsalis mostly because of loss of sensations.

Voluntary movements

There is lack of coordination of movements **(ataxia).** Normal movements like walking also become clumsy. The gait is awkward. Every movement of the limb is exaggerated while walking. Patient keeps the leg apart, raises the leg very high and stamps it down forcibly. This is called **stamping gait.**

Urinary bladder

If sacral segments are affected in tabes dorsalis, the smooth muscles of the urinary bladder become hypotonic. Micturition reflexes are lost. And the urinary bladder becomes **atonic bladder** (Chapter 57).

3. *Multiple Sclerosis*

Multiple sclerosis (MS) is a chronic and progressive inflammatory disease characterized by demyelination in brain and spinal cord. It affects the myelinated nerve fibers of brain, spinal cord and optic nerve and causes gradual destruction of myelin sheath **(demyelination).** When the disease progresses, there is transection of axons in patches throughout brain and spinal cord. The term sclerosis refers to scars (scleroses) in the myelin sheath.

Cause

Cause of multiple sclerosis is unknown. It is hypothesized that multiple sclerosis occurs due to combination and interaction of environmental factors (chemicals, bacteria and virus) and genetic factors resulting in abnormal reactions of immune system. During the process, the immune system attacks the myelin sheath.

Signs and symptoms

Initial attack by multiple sclerosis is often mild or asymptomatic. As the disease progresses variety of symptoms start appearing. Symptoms become severe during further progress of the disease.

Common initial symptoms:

1. Mild disturbance in the sensations on face, arms and legs
2. Weakness and disturbances in maintenance of posture
3. Double vision followed by partial blindness.

Other symptoms when the disease progresses:

1. Tremor, fatigue and muscle spasms
2. Speech difficulty
3. Difficulty in performing day-to-day activities
4. Bowel problems
5. Bladder dysfunction
6. Emotional outbursts like anxiety, anger and frustration
7. Short-term memory loss
8. Complete blindness
9. Development of suicidal tendency.

4. *Disk Prolapse*

Intervertebral or **spinal disk** is the cartilagenous structure of vertebral column that separates each vertebra. It is made up of a tough outer fibrous layer and a soft inner part. Inner part acts as a shock absorber and cushions the vertebrae while moving. A small gap in between the adjacent vertebrae allows nerve roots to enter or leave the spinal cord.

Rupture of disk is called disk prolapse. During disk prolapse, the soft inner material bulges out through a weak area in the hard outer layer. The bulged disk material may irritate or compress or damage the nerve root that passes through the gap between the vertebrae. Severity of the condition depends upon the degree of bulging.

Causes

1. Injury to spinal cord, neck or back
2. Heavy weight lifting
3. Sitting for a long time
4. Sudden violent twisting of the body involving spine
5. Aging: Because of gradual degeneration of disk with age. After about 30 years of age, the disk starts dehydrating. So it is more susceptible for rupture at the age of 30 to 40 years.

Symptoms

Symptoms of disk prolapse include pain and weakness in the area of prolapse. Most common area of disk

prolapse is the lower part of vertebral column. If it compresses the sciatic nerve, the symptoms become more severe. Pain spreads down the back of leg to ankle, heel or toes of foot. Lower limb cannot be lifted sometimes. There is numbness and tingling in the affected region. Sitting for long period aggravates the pain and develops other symptoms such as sneezing, coughing or voiding of urine. Prolonged compression of sciatic nerve leads to weakness of leg muscles.

Next common area of disk prolapse is the neck. In this case, the pain is felt in neck, shoulder blade and armpit. If the nerves supplying upper limbs are compressed, the pain spreads through the arm up to the fingers. It also causes stiffness, weakness or tingling in the upper limbs. Even the movements of fingers or arm are restricted.

Somatosensory System and Somatomotor System

Chapter 144

- SOMATOSENSORY SYSTEM
  - DEFINITION AND TYPES OF SENSATIONS
  - TYPES OF SOMATIC SENSATIONS
  - SENSORY PATHWAYS
  - SENSORY FIBERS OF TRIGEMINAL NERVE
  - LEMNISCUS
  - APPLIED PHYSIOLOGY
- SOMATOMOTOR SYSTEM
  - MOTOR ACTIVITIES OF THE BODY
  - SOMATOMOTOR SYSTEM
  - SPINAL CORD AND CRANIAL NERVE NUCLEI
  - CEREBRAL CORTEX
  - CEREBELLUM
  - BASAL GANGLIA
  - CLASSIFICATION OF MOTOR PATHWAYS
  - UPPER MOTOR NEURON AND LOWER MOTOR NEURON
  - APPLIED PHYSIOLOGY

SOMATOSENSORY SYSTEM

DEFINITION AND TYPES OF SENSATIONS

Somatosensory system is defined as the sensory system associated with different parts of the body.

Sensations are of two types:

1. Somatic sensations
2. Special sensations.

1. *Somatic Sensations*

Somatic sensations are the sensations arising from skin, muscles, tendons and joints. These sensations have **specific receptors,** which respond to a particular type of stimulus.

2. *Special Sensations*

Special sensations are the **complex sensations** for which the body has some **specialized sense organs.** These sensations are usually called special senses. Sensations of vision, hearing, taste and smell are the special sensations.

This chapter deals with somatic sensations.

TYPES OF SOMATIC SENSATIONS

Generally, somatic sensations are classified into three types:

1. Epicritic sensations
2. Protopathic sensations
3. Deep sensations.

1. *Epicritic Sensations*

Epicritic sensations are the mild or light sensations. Such sensations are perceived more accurately.

Epicritic sensations are:

i. Fine touch or tactile sensation (Chapter 143)
ii. Tactile localization (Chapter 143)

iii. Tactile discrimination (Chapter 143)
iv. Temperature sensation with finer range between 25°C and 40°C.

2. *Protopathic Sensations*

Protopathic sensations are the **crude sensations.** These sensations are primitive type of sensations.

Protopathic sensations are:

i. Pressure sensation (Chapter 143)
ii. Pain sensation (Chapter 143)
iii. Temperature sensation with a wider range, i.e. above 40°C and below 25°C.

3. *Deep Sensations*

Deep sensations are sensations arising from deeper structures beneath the skin and visceral organs.

Deep sensations are:

i. **Sensation of vibration** or **pallesthesia,** which is the combination of touch and pressure sensation (Chapter 143)
ii. **Kinesthetic sensation** or **kinesthesia**: Sensation of position and movements of different parts of the body. This sensation arises from the proprioceptors present in muscles, tendons, joints and ligaments. Proprioceptors are the receptors, which give response during various movements of a joint.
Kinesthetic sensation is of two types:
   a. **Conscious kinesthetic sensation** (Chapter 143)
   b. **Subconscious kinesthetic** sensation (Chapter 143). Impulses of this sensation are called non-sensory impulses.
iii. **Visceral sensations** arising from viscera (Fig. 144.1).

Synthetic Senses

Synthetic senses are the sensations synthesized at cortical level, by integration of impulses of basic sensations. Two or more basic sensations are combined in some of the synthetic senses. Best examples of synthetic senses are vibratory sensation, stereognosis and two-point discrimination.

■ SENSORY PATHWAYS

Nervous pathways of sensations are called the sensory pathways. These pathways carry the impulses from receptors in different parts of the body to centers in brain.

Sensory pathways are of two types:
1. Pathways of somatosensory system
2. Pathways of viscerosensory system.

Pathways of somatosensory system convey the information from sensory receptors in skin, skeletal muscles and joints. Pathways of this system are constituted by somatic nerve fibers called somatic afferent nerve fibers.

Pathways of viscerosensory system convey the information from receptors of the viscera. Pathways of this system are constituted by visceral or autonomic fibers.

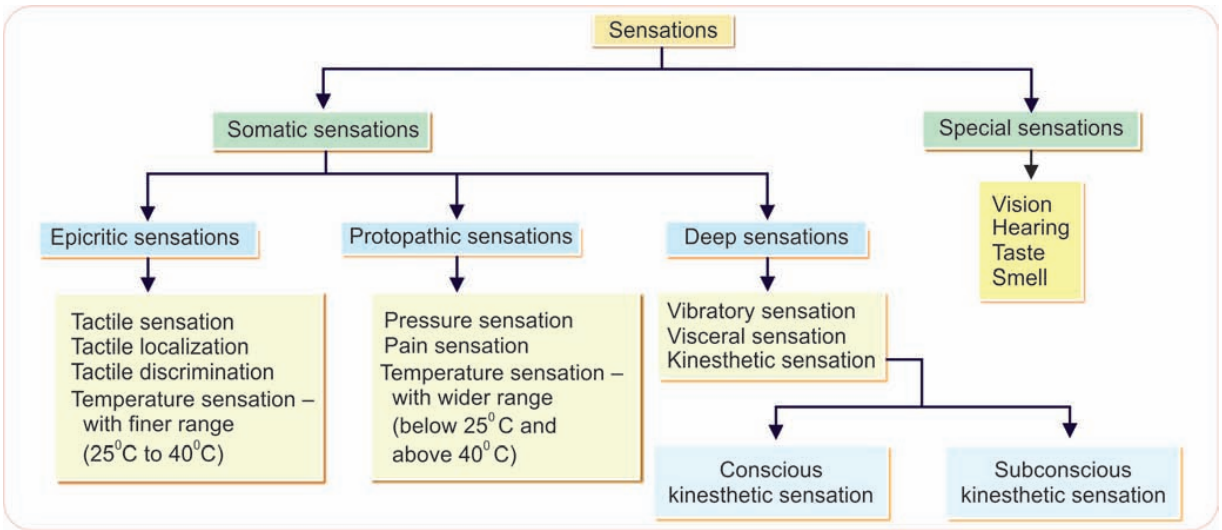

FIGURE 144.1: Classification of sensations

This chapter deals mainly with the somatosensory system.

Somatosensory Pathways

Each sensory pathway is constituted by two or three groups of neurons:

i. First order neurons
ii. Second order neurons
iii. Third order neurons.

Details of these neurons are given in Chapter 143. Pathways of some sensations like kinesthetic sensation have only first and second order neurons.

Details of pathways are given in Table 144.1. Diagrams of pathways are given in Chapter 143, along with ascending tracts of spinal cord.

■ SENSORY FIBERS OF TRIGEMINAL NERVE

Trigeminal nerve carries somatosensory information from face, teeth, periodontal tissues (tissues around teeth), oral cavity, nasal cavity, cranial dura mater and major part of scalp to sensory cortex. It also conveys proprioceptive impulses from the extrinsic muscles of the eyeball.

Origin

Sensory fibers of trigeminal nerve arise from the trigeminal ganglion situated near temporal bone. Peripheral processes of neurons in this ganglion form three divisions of trigeminal nerve, namely ophthalmic, mandibular and maxillary divisions. Cutaneous distribution of the three divisions of trigeminal nerve is shown in Figure 144.2.

Central processes from neurons of trigeminal ganglion enter pons in the form of sensory root.

Termination

After reaching the pons, fibers of sensory root divide into two groups, namely descending fibers and ascending fibers. Descending fibers terminate on primary sensory nucleus and spinal nucleus of trigeminal nerve. Primary sensory nucleus is situated in pons. Spinal nucleus of trigeminal nerve is situated below the primary sensory nucleus and extends up to the upper segments of spinal cord.

Ascending fibers of sensory root terminate in the mesencephalic nucleus of trigeminal nerve, situated in brainstem above the level of primary sensory nucleus (Fig. 144.3).

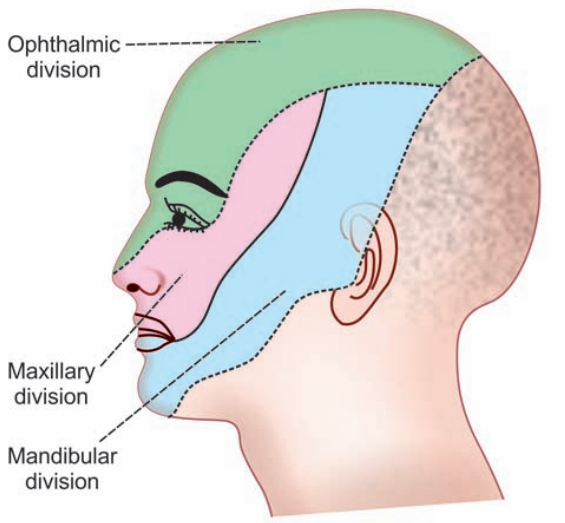

FIGURE 144.2: Cutaneous distribution (sensory) of the three divisions of trigeminal nerve

Central Connections

Majority of fibers from the primary sensory nucleus and spinal nucleus of trigeminal nerve ascend in the form of trigeminal lemniscus and terminate in ventral posteromedial nucleus of thalamus in the opposite side. Remaining fibers from these two nuclei terminate on the thalamic nucleus of same side. From thalamus, the fibers pass via superior thalamic radiation and reach the somatosensory areas of cerebral cortex.

Primary sensory nucleus and spinal nucleus of trigeminal nerve relay the sensations of touch, pressure, pain and temperature from the regions mentioned above.

Fibers from mesencephalic nucleus form the trigeminocerebellar tract that enters spinocerebellum via the superior cerebellar peduncle of the same side. This nucleus conveys proprioceptive impulses from facial muscles, muscles of mastication and ocular muscles.

■ LEMNISCUS

Lemniscus or fillet is the prominent bundle of sensory nerves in brain.

Lemniscus is of four types:

1. **Spinal lemniscus** formed by spinothalamic tracts in medulla oblongata
2. **Lateral lemniscus** formed by the fibers carrying sensation of hearing from cochlear nuclei to inferior colliculus and medial geniculate body

TABLE 144.1: Sensory pathways

Sensation	Receptor	First order neuron in	Second order neuron in	Third order neuron in	Center
Fine touch Tactile localization Tactile discrimination Vibratory sensation Stereognosis	Meissner corpuscles and Merkel disc	Posterior nerve root ganglion – Fibers form Fasciculus gracilis and Fasciculus cuneatus	Nucleus gracilis and Nucleus cuneatus – Fibers form internal arcuate fibers	Ventral posterolateral nucleus of thalamus	Sensory cortex
Pressure Crude touch	Pacinian corpuscle	Posterior nerve root ganglion	Chief sensory nucleus – Fibers form anterior spinothalamic tract	Ventral posterolateral nucleus of thalamus	Sensory cortex
Temperature	Warmth – Ruffini end bulb Cold – Krause end bulb	Posterior nerve root ganglion	Substantia gelatinosa – Fibers form lateral spinothalamic tract	Ventral posterolateral nucleus of thalamus	Sensory cortex
Conscious kinesthetic sensation	Proprioceptors – Muscle spindle Golgi tendon apparatus	Posterior nerve root ganglion – Fibers form Fasciculus gracilis and Fasciculus cuneatus	Nucleus gracilis and Nucleus cuneatus – Fibers form internal arcuate fibers	Ventral posterolateral nucleus of thalamus	Sensory cortex
Subconscious kinesthetic sensation	Proprioceptors – Muscle spindle Golgi tendon apparatus	Posterior nerve root ganglion	Nucleus of Clarke and Marginal nucleus – Fibers form dorsal and ventral spinocerebellar tracts	–	Anterior lobe of cerebellum
Pain	Free nerve endings	Posterior nerve root ganglion Fast pain – A δ-fibers Slow pain – C fibers	Fast pain – marginal nucleus in spinal cord Slow pain – substantia gelatinosa of Rolando Fibers form lateral spinothalamic tract	Ventral posterolateral nucleus of thalamus, reticular formation and midbrain	Sensory cortex

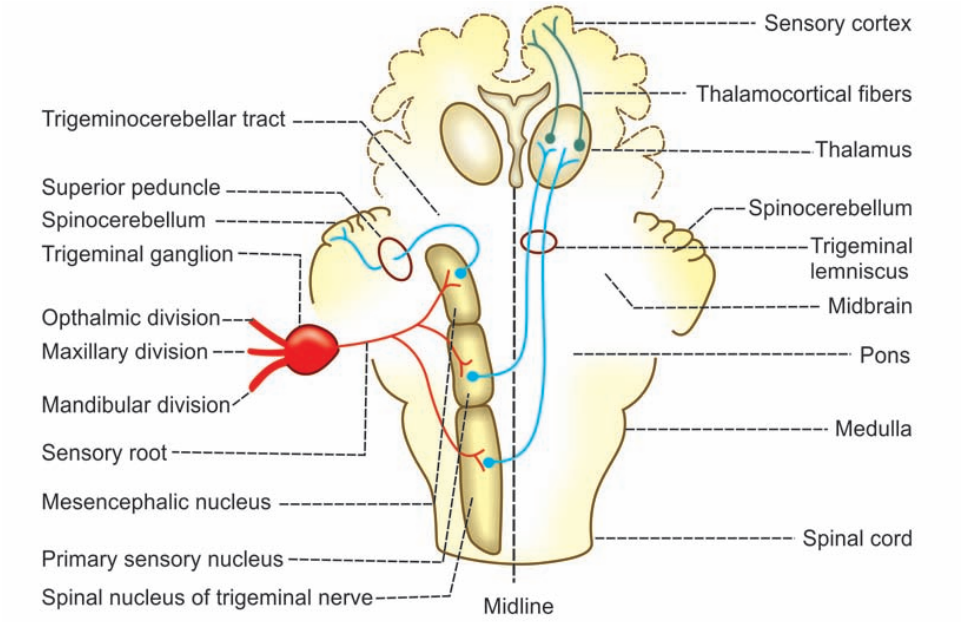

FIGURE 144.3: Diagrammatic representation of trigeminal pathway. Trigeminal lemniscus carries impulses of touch, pressure, pain and temperature sensations to somatosensory cortex. Trigeminocerebellar tract carries proprioceptive impulses to spinocerebellum.

3. **Medial lemniscus** formed by fibers arising from nucleus cuneatus and nucleus gracilis
4. **Trigeminal lemniscus** formed by fibers from sensory nuclei of trigeminal nerve. This lemniscus carries general senses from head, neck, face, mouth, eyeballs and ears.

■ APPLIED PHYSIOLOGY

Lesions or other nervous disorders in sensory pathway affect the sensory functions of the body. The effects are given in Table 144.2.

■ SOMATOMOTOR SYSTEM

■ MOTOR ACTIVITIES OF THE BODY

Motor activities of the body depend upon different groups of tissues of the body.

Motor activities are divided into two types:

1. Activities of skeletal muscles, which are involved in posture and movement
2. Activities of smooth muscles, cardiac muscles and other tissues, which are involved in the functions of various visceral organs.

Activities of skeletal muscles (voluntary functions) are controlled by somatomotor system, which is constituted by the somatic motor nerve fibers. Activities of tissues or visceral organs (involuntary functions) are controlled by visceral or autonomic nervous system, which is constituted by the sympathetic and parasympathetic systems. Autonomic nervous system is described in Chapter 164.

This chapter deals with somatomotor system.

■ SOMATOMOTOR SYSTEM

Movements of the body depend upon different groups of skeletal muscles. Various types of movements or motor activities brought about by these muscles are:

1. Execution of smooth, precise and accurate voluntary movements
2. Coordination of movements responsible for skilled activities
3. Coordination of movements responsible for the maintenance of posture and equilibrium.

Voluntary actions and postural movements are carried out by not only the simple contraction and relaxation of skeletal muscles but also the adjustments of tone in these muscles. The execution,

TABLE 144.2: Effects of disorders of sensory pathways

No	Condition	Definition
1.	Anesthesia	Loss of all sensations
2.	Hyperesthesia	Increased sensitivity to sensory stimuli
3.	Hypoesthesia	Reduction in sensitivity to stimuli
4.	Hemiesthesia	Loss of all sensations in one side of body
5.	Paresthesia	Abnormal sensations such as tingling, burning, prickling and numbness
6.	Hemiparesthesia	Abnormal sensations in one side of body
7.	Dissociated anesthesia	Loss of some sensations while other sensations are intact
8.	General anesthesia	Loss of all sensations with loss of consciousness produced by anesthetic agents
9.	Local anesthesia	Loss of sensations in a restricted area of the body
10.	Spinal anesthesia	Loss of sensations due to spinal cord lesion or anesthetic agents injected beneath the coverings of spinal cord
11.	Tactile anesthesia	Loss of tactile sensations
12.	Tactile hyperesthesia	Increased sensitivity to tactile stimuli
13.	Analgesia	Loss of pain sensation
14.	Hyperalgesia	Increased sensitivity to pain stimulus
15.	Paralgesia	Abnormal pain sensation
16.	Thermoanesthesia or thermanesthesia or thermanalgesia	Loss of thermal sensation
17.	Pallanesthesia	Loss of sensation of vibration
18.	Astereognosis	Loss of ability to recognize known object with closed eyes due to loss of cutaneous sensations
19.	Illusion	Mental depression due to misinterpretation of a sensory stimulus
20.	Hallucination	Feeling of a sensation without any stimulus

planning, coordination and adjustments of movements of the body are under the influence of different parts of nervous system, which are together called motor system. Sensory system of the body also plays a vital role in the control of movements.

Spinal reflexes are responsible for most of the movements concerned with voluntary actions and posture. Stimulation of receptor activates the motor neuron in spinal cord, leading to the contraction of muscle innervated by spinal motor neuron. Apart from these reflexes, signals for voluntary motor activities are also sent from different areas of the brain, particularly the cerebral cortex to spinal motor neurons.

Coordination and control of movements initiated by cerebral cortex depends upon two factors:

1. Feedback signals from proprioceptors in muscle and other sensory receptors
2. Interaction of other parts of brain such as brainstem, cerebellum and basal ganglia.

Thus, the motor system includes spinal cord and its nerves, cranial nerves, brainstem, cerebral cortex, cerebellum and basal ganglia. Neuronal circuits between these parts of nervous system, which are responsible for the motor activities are called the motor pathways. Classification of motor pathways is given in the later part of this chapter because the knowledge of role of different parts of nervous system is essential to understand the classification of the motor pathways.

■ SPINAL CORD AND CRANIAL NERVE NUCLEI

Motor Neurons

Activities of skeletal muscles are executed by the impulses discharged from alpha motor neurons situated in ventral (anterior) gray horn of spinal cord and nuclei of many of the cranial nerves present in brainstem.

Alpha motor neurons in the spinal cord, which innervate the **extrafusal fibers** of skeletal muscles are responsible for the contraction of muscles in upper limbs, trunk and lower part of the body. The **gamma motor neurons,** which innervate the **intrafusal fibers** of

muscle, are responsible for the maintenance of muscle tone.

Motor neurons of the cranial nerve nuclei situated in brainstem send their signals to the muscles of neck and upper part of trunk via cranial nerves.

Final Common Pathway

Activities of a particular skeletal muscle depend upon the excitation of alpha motor neuron (also known as **lower motor neuron**) in the spinal cord or cranial nerve nuclei. This is the only pathway, through which the signals from other parts of nervous system reach the muscles (Fig. 144.4). Hence, the alpha motor neurons are called **'final common pathway'** of motor system.

Functions of Motor Neurons

Motor neurons responsible for the contraction of skeletal muscles are arranged topographically in the ventral gray horn of spinal cord. Neurons situated in the medial part of ventral gray horn innervate the muscles near midline of the body called **axial muscles** and muscles in the proximal portions of limbs called **proximal muscles.** These two types of muscles are involved in the adjustment of posture and gross movement. Motor neurons in lateral part of ventral gray horn innervate the muscles in distal portions of the limbs called **distal muscles.** Distal muscles are involved in the well coordinated skilled voluntary movements.

Motor neurons in cranial nerve nuclei of brainstem innervate the extrinsic muscles of eyeball and muscles of face, tongue, neck and upper part of trunk. These muscles are concerned with ocular movements and movements of facial expressions, chewing, swallowing and movements of head and shoulder. Motor neurons are situated in the nuclei of cranial nerves III, IV, V, VI, VII, IX, X, XI and XII.

■ CEREBRAL CORTEX

Cortical areas concerned with origin of motor signals are the primary motor area, premotor area and supplementary motor area in frontal lobe and sensory area in the parietal lobe. Details of the cortical areas are given in Chapter 152.

Cortical areas send their output signals to spinal cord via corticospinal tracts and to brainstem via corticobulbar tracts. About 30% of the fibers forming corticospinal and corticobulbar tracts take their origin from primary and supplementary motor cortex, 30% from premotor area and remaining 40% from parietal lobe particularly from somatosensory area.

■ CEREBELLUM

Cerebellum plays an important role in planning, programming and integrating the skilled voluntary movements. It is also concerned with the maintenance of muscle tone, posture and equilibrium. Cerebellum

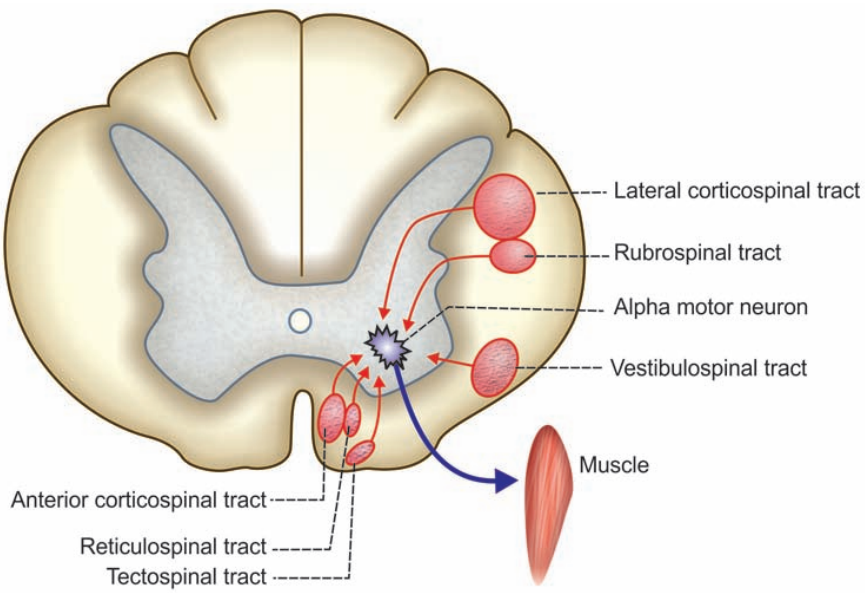

FIGURE 144.4: Final common pathway

receives impulses from proprioceptors of muscle, vestibular apparatus, cerebral cortex, brainstem and basal ganglia. It interprets these impulses and sends signals to motor cortex, reticular formation and nuclei of brainstem.

Role of cerebellum in motor functions is described in detail in Chapter 150.

■ BASAL GANGLIA

Basal ganglia play an important role in the coordination of skilled movements, regulation of automatic associated movements and control of muscle tone by sending output signals to motor cortex, reticular formation and spinal cord. Functions of basal ganglia are explained in Chapter 151.

■ CLASSIFICATION OF MOTOR PATHWAYS

There are two methods to classify the motor pathways. In the first method of classification, motor pathways are divided into pyramidal and extrapyramidal tracts. In the second method, motor pathways are classified into lateral and medial systems.

Pyramidal and Extrapyramidal Pathways

Motor pathways are classified into pyramidal and extrapyramidal tracts, depending upon the situation of their fibers in medulla oblongata.

Pyramidal tracts

Pyramidal tracts are those fibers which form the pyramids in upper part of medulla. Pyramidal tracts are the anterior and lateral corticospinal tracts. These tracts control the **voluntary movements** of the body (Chapter 143).

Extrapyramidal tracts

Motor pathways other than pyramidal tracts are known as extrapyramidal tracts.

Extrapyramidal tracts are:

1. Medial longitudinal fasciculus
2. Anterior and lateral vestibulospinal tracts
3. Reticulospinal tract
4. Tectospinal tract
5. Reticulospinal tract
6. Rubrospinal tract
7. Olivospinal tract.

Extrapyramidal tracts are concerned with the regulation of tone, posture and equilibrium (Chapter 143).

Lateral and Medial Motor Systems

Depending upon the location or termination, motor pathways are divided into two categories, namely the lateral system or pathway and the medial system or pathway. Lateral motor system is phylogenetically new and medial motor system is old.

Lateral motor system

Fibers of this system terminate on motor neurons situated in lateral part of ventral gray horn in spinal cord (directly or via interneurons) and on equivalent motor neurons of cranial nerve nuclei in brainstem.

Components of lateral system:

1. Lateral corticospinal tract, which arises from different areas of cerebral cortex and terminates in the alpha motor neurons situated in lateral part of ventral gray horn of spinal cord. Other details of this tract are given in Chapter 143.
2. Rubrospinal tract, which arises from red nucleus in midbrain (Chapter 143)
3. Part of corticobulbar tract, which arises from different areas of frontal and parietal lobes of cerebral cortex along with corticospinal tracts. Part of corticobulbar tract belonging to lateral motor system terminates on the nucleus of hypoglossal nerve and motor nucleus of facial nerve. Fibers from hypoglossal nerve innervate the muscles of tongue. Fibers from motor nucleus of facial nerve innervate the muscles of lower part of face.

Functions of lateral motor system:

1. Lateral corticospinal tract activates the muscles of distal portions of limbs and regulates the skilled voluntary movements
2. Rubrospinal tract facilitates the tone in the muscles, particularly the flexor muscles
3. Corticobulbar fibers of lateral system are concerned with the movements of expression in lower part of face and movements of tongue.

Medial motor system

Fibers of medial motor system terminate on motor neurons situated in the medial part of ventral gray horn of spinal cord (via interneurons) and on equivalent motor neurons of cranial nerve nuclei, situated in the brainstem.

Components of medial motor system:

1. Anterior corticospinal tract, which arises from different areas of cerebral cortex and terminates in the alpha motor neurons situated in medial part of ventral gray horn of spinal cord (Chapter 143).

2. Part of corticobulbar fibers of medial system, which arises from different areas of frontal and parietal lobes of cerebral cortex along with corticospinal tracts. Fibers of corticobulbar tract belonging to medial motor system innervate the muscles of trunk and limbs, muscles of jaw and muscles of upper part of face.
3. Lateral and medial vestibulospinal tracts that arise from lateral vestibular nucleus and medial vestibular nucleus, respectively (Chapter 143)
4. Reticulospinal tract, which arises from reticular formation in brainstem (Chapter 143)
5. Tectospinal tract, which takes origin from superior colliculus of midbrain (Chapter 143).

Functions of medial motor system:

1. Anterior corticospinal tract is responsible for the maintenance of posture and equilibrium
2. Fibers of corticobulbar tract belonging to medial motor system, innervating muscles of upper part of trunk are involved in the maintenance of posture and equilibrium. Fibers innervating muscles of jaw and face are involved in the movements of chewing and movements of eyebrow.
3. Vestibulospinal tract is concerned with the adjustment of position of head and body during angular and linear acceleration
4. Pontine fibers of reticulospinal tract facilitate the tone of extensor muscles and regulate the postural reflexes. However, medullary fibers of this tract inhibit the tone of the muscles involved in postural movements.
5. Tectospinal tract is responsible for the movement of head in response to visual and auditory stimuli.

■ UPPER MOTOR NEURON AND LOWER MOTOR NEURON

Neurons of the motor system are divided into upper motor neurons and lower motor neurons, depending upon their location and termination.

Upper Motor Neuron

Upper motor neurons are the neurons in higher centers of brain, which control the lower motor neurons.

Upper motor neurons are of three types:

1. Motor neurons in cerebral cortex. Fibers of these neurons form corticospinal (pyramidal) and corticobulbar tracts.
2. Neurons in basal ganglia and brainstem nuclei
3. Neurons in cerebellum.

Motor neurons in cerebral cortex, which give origin to pyramidal tracts belong to the pyramidal system and the remaining motor neurons belong to extrapyramidal system.

Some controversy exists in including the neurons of extrapyramidal system under the category of upper motor neurons. However, considering in terms of the definition, neurons other than lower motor neurons are to be named as upper motor neurons.

Lower Motor Neuron

Lower motor neurons are the anterior gray horn cells in spinal cord and motor neurons of cranial nerve nuclei, situated in brainstem, which innervate the muscles directly.

Thus, the lower motor neurons constitute 'final common pathway' of motor system. Lower motor neurons are under the influence of upper motor neurons.

TABLE 144.3: Effects of upper motor neuron lesion and lower motor neuron lesion

	Effects	Upper motor neuron lesion	Lower motor neuron lesion
Clinical observation	1. Muscle tone	Hypertonia	Hypotonia
	2. Paralysis	Spastic type of paralysis	Flaccid type of paralysis
	3. Wastage of muscle	Wastage of muscle occurs	Wastage of muscle occurs
	4. Superficial reflexes	Lost	Lost
	5. Plantar reflex	Abnormal plantar reflex – Babinski sign	Absent
	6. Deep reflexes	Exaggerated	Lost
	7. Clonus	Present	Absent
Clinical confirmation	8. Electrical activity	Normal	Absent
	9. Muscles affected	Groups of muscles are affected	Individual muscles are affected
	10. Fascicular twitch in EMG	Absent	Present

TABLE 144.4: Types of paralysis

Paralysis	Parts of the body affected	Causes
Monoplegia	Paralysis of one limb	Isolated damage of central nervous system or peripheral nervous system
Diplegia	Paralysis of both the upper limbs or both the lower limbs	Isolated damage of brain
Hemiplegia	Paralysis of upper limb and lower limb on one side of the body	Lesion in motor cortex and corticospinal tracts in posterior limb of internal capsule on the side opposite to the paralysis
Paraplegia	Paralysis of lower half of the body	Injury to lower part of spinal cord
Quadriplegia or tetraplegia	Paralysis of all the four limbs	Injury to upper part of spinal cord (shoulder level or above, at which the motor nerves of upper limbs leave the spinal cord)

■ APPLIED PHYSIOLOGY

Effects of Motor Neuron Lesions

Effects of lesions of upper motor neurons and lower motor neurons are given in Table 144.3. Effects of lower motor neuron lesion are the loss of muscle tone and flaccid paralysis.

Effects of upper motor neuron lesion depends upon the type of neuron involved. Effects of upper motor neuron lesion are:

1. Lesion in pyramidal system causes **hypertonia** and **spastic paralysis.** Spastic paralysis involves only one group of muscles, particularly the extensor muscles.
2. Lesion in basal ganglia produces hypertonia and **rigidity** involving both flexor and extensor muscles
3. Lesion in cerebellum causes hypotonia, muscular weakness and incoordination of movements.

Paralysis

Paralysis is defined as the complete loss of strength and functions of muscle group or a limb.

Causes for paralysis

Common causes for paralysis are trauma, tumor, stroke, cerebral palsy (condition caused by brain injury immediately after birth), multiple sclerosis (Chapter 143) and neurodegenerative diseases.

Types of paralysis

Paralysis of muscles in the body depends upon type and location of motor neurons affected by the lesion. Different types of paralysis are given in Table 144.4.

Physiology of Pain

Chapter 145

- INTRODUCTION
- BENEFITS OF PAIN SENSATION
- COMPONENTS OF PAIN SENSATION
- PATHWAYS OF PAIN SENSATION
  - FROM SKIN AND DEEPER STRUCTURES
  - FROM FACE
  - FROM VISCERA
  - FROM PELVIC REGION
- VISCERAL PAIN
  - CAUSES OF VISCERAL PAIN
- REFERRED PAIN
  - DEFINITION
  - EXAMPLES OF REFERRED PAIN
  - MECHANISM OF REFERRED PAIN
- NEUROTRANSMITTERS INVOLVED IN PAIN SENSATION
- ANALGESIA SYSTEM
  - ANALGESIC PATHWAY
- GATE CONTROL THEORY
- APPLIED PHYSIOLOGY

INTRODUCTION

Pain is defined as an unpleasant and emotional experience associated with or without actual tissue damage. Pain sensation is described in many ways like sharp, pricking, electrical, dull ache, shooting, cutting, stabbing, etc. Often it induces crying and fainting.

Pain is produced by real or potential injury to the body. Often it is expressed in terms of injury. For example, pain produced by fire is expressed as burning sensation; pain produced by severe sustained contraction of skeletal muscles is expressed as cramps.

Pain may be acute or chronic. **Acute pain** is a sharp pain of short duration with easily identified cause. Often it is localized in a small area before spreading to neighboring areas. Usually it is treated by medications. **Chronic pain** is the intermittent or constant pain with different intensities. It lasts for longer periods. It is somewhat difficult to treat chronic pain and it needs professional expert care.

BENEFITS OF PAIN SENSATION

Pain is an important sensory symptom. Though it is an unpleasant sensation, it has protective or survival benefits such as:

1. Pain gives warning signal about the existence of a problem or threat. It also creates awareness of injury.
2. Pain prevents further damage by causing reflex withdrawal of the body from the source of injury
3. Pain forces the person to rest or to minimize the activities thus enabling rapid healing of injured part
4. Pain urges the person to take required treatment to prevent major damage.

■ COMPONENTS OF PAIN SENSATION

Pain sensation has two components:

1. Fast pain
2. Slow pain.

Fast pain is the first sensation whenever a pain stimulus is applied. It is experienced as a bright, sharp and localized pain sensation. Fast pain is followed by the slow pain, which is experienced as a dull, diffused and unpleasant pain.

Receptors for both the components of pain are same, i.e. the free nerve endings. But, afferent nerve fibers are different. Fast pain sensation is carried by Aδ fibers and slow pain sensation is carried by C type of nerve fibers.

■ PATHWAYS OF PAIN SENSATION

Pain sensation from various parts of body is carried to brain by different pathways which are:

1. Pathway from skin and deeper structures
2. Pathway from face
3. Pathway from viscera
4. Pathway from pelvic region.

■ 1. FROM SKIN AND DEEPER STRUCTURES

Receptors

Receptors of pain sensation are the free nerve endings, which are distributed throughout the body.

First Order Neurons

First order neurons are the cells in posterior nerve root ganglia, which receive the impulses of pain sensation from pain receptors through their dendrites. These impulses are transmitted to spinal cord through the axons of these neurons.

Fast pain fibers

Fast pain sensation is carried by Aδ type afferent fibers which synapse with neurons of **marginal nucleus** in the posterior gray horn.

Slow pain fibers

Slow pain sensation is carried by C type afferent fibers, which synapse with neurons of **substantia gelatinosa** of Rolando in the posterior gray horn (Fig. 143.4).

Second Order Neurons

Neurons of marginal nucleus and substantia gelatinosa of Rolando form the second order neurons. Fibers from these neurons ascend in the form of the lateral spinothalamic tract.

Fast pain fibers

Fibers of fast pain arise from neurons of marginal nucleus. Immediately after taking origin, the fibers cross the midline via anterior gray commissure, reach the lateral white column of the opposite side and ascend. These fibers form the neospinothalamic fibers in lateral spinothalamic tract. These nerve fibers terminate in **ventral posterolateral nucleus** of thalamus. Some of the fibers terminate in ascending reticular activating system of brainstem.

Slow pain fibers

Fibers of slow pain, which arise from neurons of substantia gelatinosa, cross the midline and run along the fibers of fast pain as **paleospinothalamic fibers** in lateral spinothalamic tract. One fifth of these fibers terminate in ventral posterolateral nucleus of thalamus. Remaining fibers terminate in any of the following areas:

i. Nuclei of reticular formation in brainstem
ii. Tectum of midbrain
iii. Gray matter surrounding aqueduct of Sylvius.

Third Order Neurons

Third order neurons of pain pathway are the neurons in:

i. Thalamic nucleus
ii. Reticular formation
iii. Tectum
iv. Gray matter around aqueduct of Sylvius.

Axons from these neurons reach the sensory area of cerebral cortex (Fig. 145.2). Some fibers from reticular formation reach hypothalamus.

Center for Pain Sensation

Center for pain sensation is in postcentral gyrus of parietal cortex. Fibers reaching hypothalamus are concerned with arousal mechanism due to pain stimulus.

■ 2. FROM FACE

Pain sensation from face is carried by trigeminal nerve (Chapter 144).

■ 3. FROM VISCERA

Pain sensation from thoracic and abdominal viscera is transmitted by sympathetic (thoracolumbar) nerves. Pain from esophagus, trachea and pharynx is carried by vagus and glossopharyngeal nerves.

4. FROM PELVIC REGION

Pain sensation from deeper structures of pelvic region is conveyed by sacral parasympathetic nerves.

VISCERAL PAIN

Pain from viscera is unpleasant. It is poorly localized.

CAUSES OF VISCERAL PAIN

1. *Ischemia*

Substances released during ischemic reactions such as bradykinin and proteolytic enzymes stimulate the pain receptors of viscera.

2. *Chemical Stimuli*

Chemical substances like acidic gastric juice, leak from ruptured ulcers into peritoneal cavity and produce pain.

3. *Spasm and Overdistention of Hollow Organs*

Spastic contraction of smooth muscles in gastrointestinal tract and other hollow organs of viscera cause pain by stimulating the free nerve endings. Overdistention of hollow organs also causes pain.

REFERRED PAIN

DEFINITION

Referred pain is the pain that is perceived at a site adjacent to or away from the site of origin. Deep pain and some visceral pain are referred to other areas. But, superficial pain is not referred.

EXAMPLES OF REFERRED PAIN

1. Cardiac pain is felt at inner part of left arm and left shoulder (Fig. 145.1)
2. Pain in ovary is referred to umbilicus
3. Pain from testis is felt in abdomen
4. Pain in diaphragm is referred to shoulder
5. Pain in gallbladder is referred to epigastric region
6. Renal pain is referred to loin.

MECHANISM OF REFERRED PAIN

Dermatomal Rule

According to dermatomal rule, pain is referred to a structure, which is developed from the same **dermatome** from which the pain producing structure is developed.

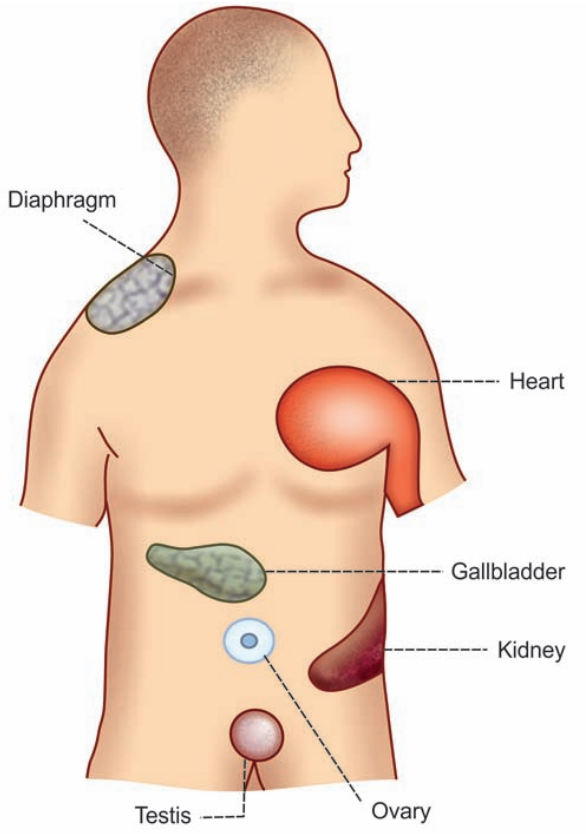

FIGURE 145.1: Sites of referred pain

A dermatome includes all the structures or parts of the body, which are innervated by afferent nerve fibers of one dorsal root. For example, the heart and inner aspect of left arm originate from the same dermatome. So, the pain in heart is referred to left arm.

NEUROTRANSMITTERS INVOLVED IN PAIN SENSATION

Glutamate and substance P are the neurotransmitters secreted by pain nerve endings. Aδ afferent fibers, which transmit impulses of fast pain secrete glutamate. The C type fibers, which transmit impulses of slow pain secrete substance P.

ANALGESIA SYSTEM

Analgesia system means the pain control system. Body has its own analgesia system in brain, which provides a short-term relief from pain. It is also called

endogenous analgesic system. Analgesia system has got its own pathway through which it blocks the synaptic transmission of pain sensation in spinal cord and thus attenuates the experience of pain. In fact analgesic drugs such as opioids act through this system and provide a controlled pain relief.

■ ANALGESIC PATHWAY

Analgesic pathway that interferes with pain transmission is often considered as descending pain pathway, the ascending pain pathway being the afferent fibers that transmit pain sensation to the brain (Fig. 145.2).

Role of Analgesic Pathway in Inhibiting Pain Transmission

1. Fibers of analgesic pathway arise from frontal lobe of cerebral cortex and hypothalamus
2. These fibers terminate in the gray matter surrounding the third ventricle and aqueduct of Sylvius (periaqueductal gray matter)
3. Fibers from here descend down to brainstem and terminate on:
   i. **Nucleus raphe magnus,** situated in reticular formation of lower pons and upper medulla
   ii. **Nucleus reticularis,** paragigantocellularis situated in medulla
4. Fibers from these reticular nuclei descend through lateral white column of spinal cord and reach the synapses of the neurons in afferent pain pathway situated in anterior gray horn
   Synapses of the afferent pain pathway are between:
   i. Aδ type afferent fibers and neurons of marginal nucleus
   ii. C type afferent fibers and neurons of substantia gelatinosa of Rolando.
5. At synaptic level, analgesic fibers release neurotransmitters and inhibit the pain transmission before being relayed to brain.

Neurotransmitters of Analgesic Pathway

Neurotransmitters released by the fibers of analgesic pathway are serotonin and opiate receptor substances namely enkephalin, dynorphin and endorphin.

■ GATE CONTROL THEORY

Psychologist **Ronald Melzack** and the anatomist **Patrick Wall** proposed the gate control theory for pain in 1965 to explain the pain suppression.

According to them, the pain stimuli transmitted by afferent pain fibers are blocked by gate mechanism

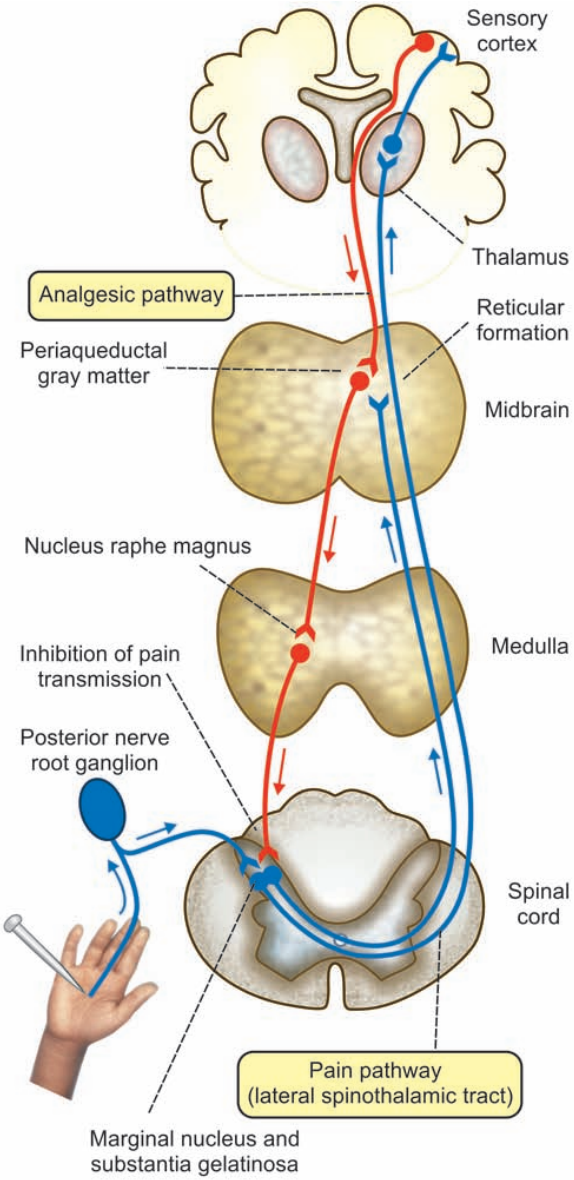

FIGURE 145.2: Pain pathway and analgesic pathway

located at the posterior gray horn of spinal cord. If the gate is opened, pain is felt. If the gate is closed, pain is suppressed.

Mechanism of Gate Control at Spinal Level

1. When pain stimulus is applied on any part of body, besides pain receptors, the receptors of other sensations such as touch are also stimulated

2. When all these impulses reach the spinal cord through posterior nerve root, the fibers of touch sensation (posterior column fibers) send collaterals to the neurons of pain pathway, i.e. cells of marginal nucleus and substantia gelatinosa
3. Impulses of touch sensation passing through these collaterals inhibit the release of glutamate and substance P from the pain fibers
4. This closes the gate and the pain transmission is blocked (Fig. 145.3).

Role of Brain in Gate Control Mechanism

According to Melzack and Wall, brain also plays some important role in the gate control system of the spinal cord as follows:

1. If the gates in spinal cord are not closed, pain signals reach thalamus through lateral spinothalamic tract
2. These signals are processed in thalamus and sent to sensory cortex

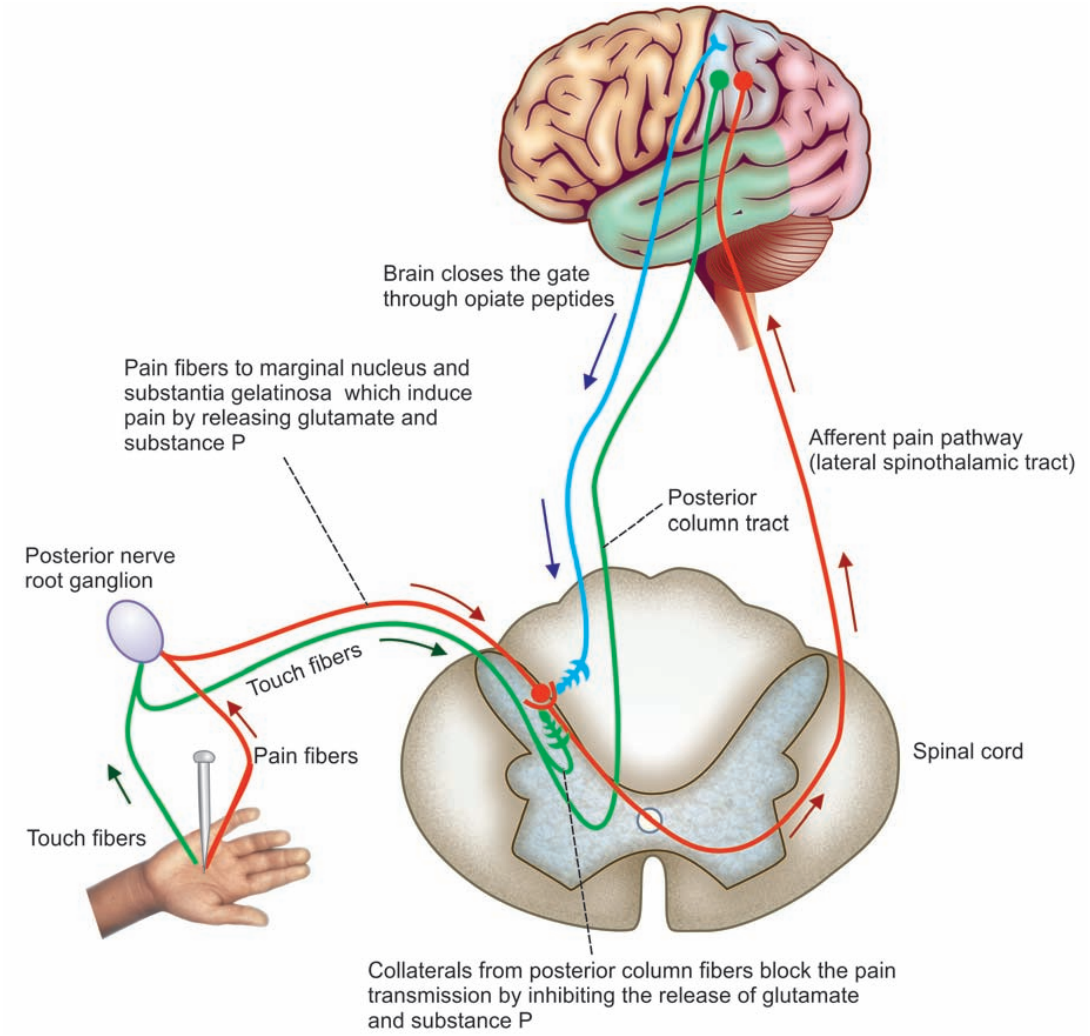
Brain closes the gate through opiate peptides
Pain fibers to marginal nucleus and substantia gelatinosa which induce pain by releasing glutamate and substance P
Afferent pain pathway (lateral spinothalamic tract)
Posterior column tract
Posterior nerve root ganglion
Touch fibers
Pain fibers
Touch fibers
Spinal cord
Collaterals from posterior column fibers block the pain transmission by inhibiting the release of glutamate and substance P

FIGURE 145.3: Gate control system

3. Perception of pain occurs in cortical level in context of the person's emotional status and previous experiences
4. The person responds to the pain based on the integration of all these information in the brain. Thus, the brain determines the severity and extent of pain.
5. To minimize the severity and extent of pain, brain sends message back to spinal cord to close the gate by releasing pain relievers such as opiate peptides
6. Now the pain stimulus is blocked and the person feels less pain.

Significance of Gate Control

Thus, gating of pain at spinal level is similar to presynaptic inhibition. It forms the basis for relief of pain through rubbing, massage techniques, application of ice packs, acupuncture and electrical analgesia. All these techniques relieve pain by stimulating the release of endogenous pain relievers (opioid peptides), which close the gate and block the pain signals.

■ APPLIED PHYSIOLOGY

1. *Analgesia*

Analgesia means loss of pain sensation.

2. *Hyperalgesia*

Hyperalgesia is defined as the increased sensitivity to pain sensation.

3. *Paralgesia*

Abnormal pain sensation is called paralgesia.

Brainstem

Chapter 146

- INTRODUCTION
- MEDULLA OBLONGATA
- PONS
- MIDBRAIN
  - TECTUM
  - CEREBRAL PEDUNCLES

INTRODUCTION

Brainstem is the part of brain formed by medulla oblongata, pons and midbrain. Brainstem contains ascending and descending tracts between brain and spinal cord. It also contains many centers for regulation of vital functions in the body.

MEDULLA OBLONGATA

Medulla oblongata or medulla is the lowermost part of brain. It is situated below pons and is continued downwards as spinal cord. Medulla forms the main pathway for ascending and descending tracts of the spinal cord. It also has many important centers which control the vital functions.

1. *Respiratory Centers*

Dorsal and ventral group of neurons form the medullary respiratory centers, which maintain normal rhythmic respiration.

2. *Vasomotor Center*

Vasomotor center controls blood pressure and heart rate.

3. *Deglutition Center*

Deglutition center regulates the pharyngeal and esophageal stages of deglutition.

4. *Vomiting Center*

Vomiting center induces vomiting during irritation or inflammation of gastrointestinal (GI) tract.

5. *Superior and Inferior Salivatory Nuclei*

Salivatory nuclei control the secretion of **saliva.**

6. *Cranial Nerve Nuclei*

Nuclei of 12th, 11th, 10th and some nuclei of 8th and 5th cranial nerves are located in the medulla oblongata. 12th cranial (hypoglossal) nerve controls the movements of **tongue.** 11th cranial (accessory) nerve controls the movements of **shoulder** and 10th cranial (vagus) nerve controls almost all the **vital functions** in the body, viz. cardiovascular system, respiratory system, GI system, etc. 8th cranial nerve (the cochlear division of this nerve), which has the relay in medulla oblongata, is concerned with the auditory function.

7. *Vestibular Nuclei*

Vestibular nuclei contain the second order neurons of vestibular nerve. There are four vestibular nuclei, situated in the rostral part of medulla and caudal part of pons, namely superior, medial, lateral and inferior vestibular nuclei. Medial and inferior vestibular nuclei extend into medulla.

All the medullary centers and nuclei of cranial nerves are controlled by higher centers, situated in cerebral cortex and hypothalamus.

PONS

Pons forms a bridge between medulla and midbrain.

Functions of Pons

1. Axons of pontine nuclei join to form the middle cerebellar peduncle or the brachium pontis. Pons forms the pathway that connects cerebellum with cerebral cortex.
2. Pyramidal tracts pass through the pons
3. Medial lemniscus is joined by the fibers of 10th, 9th, 7th and 5th cranial nerves in pons
4. Nuclei of 8th, 7th, 6th and 5th cranial nerves are located in pons
5. Pons contains the pneumotaxic and apneustic centers for regulation of respiration
6. It also contains the vestibular nuclei, which are already mentioned in medulla oblongata.

MIDBRAIN

Midbrain lies between pons and diencephalon. It consists of two parts:

A. Tectum
B. Cerebral peduncles.

TECTUM

Tectum is formed by two structures:

1. Superior colliculus
2. Inferior colliculus.

1. *Superior Colliculus*

Superior colliculus is a small structure and is an important center for reflexes. Through tectospinal tract, superior colliculus controls the **movements** of the eyes, head, trunk and limbs, in response to visual impulses. Efferent fibers from superior colliculus going to the nucleus of III cranial (oculomotor) nerve cause constriction of pupil during light reflex. Thus, it forms the center for **light reflex.** Superior colliculus also receives afferents from optic tract, which helps in the integration of **optical and postural reflexes.**

2. *Inferior Colliculus*

Inferior colliculus consists of single layer of neurons to which the lateral lemniscus (auditory fibers) synapses. Inferior colliculus is the center for auditory reflexes. Stimulation of this also produces reflex vocalization.

CEREBRAL PEDUNCLES

Cerebral peduncles include:

1. Basis pedunculi
2. Substantia nigra
3. Tegmentum, which includes red nucleus.

1. *Basis Pedunculus*

Basis pedunculus consists of pyramidal tract fibers in the middle, temporopontine fibers laterally and frontopontine fibers medially.

2. *Substantia Nigra*

Substantia nigra is situated below the red nucleus. Substantia nigra is considered as one of the components of basal ganglia (Chapter 151).

3. *Tegmentum*

Tegmentum lies dorsal to substantia nigra and is actually the upward continuation of the reticular formation in pons. Tegmentum comprises three decussations and red nucleus.

Decussations in tegmentum

i. **Superior cerebellar peduncle,** which is formed by fibers between cerebellum and other parts of CNS. These fibers are predominantly efferent fibers from dentate nucleus of cerebellum; few fibers are from other cerebellar nuclei such as nucleus globosus and nucleus emboliformis.
ii. **Forel decussation,** which is due to the crossing of rubrospinal tracts from either side
iii. **Meynert decussation,** which is due to the crossing of medial longitudinal bundle that is formed by efferent fibers of 3rd, 4th and 6th cranial nerves.

Red Nucleus

Red nucleus is a large oval or round mass of gray matter, extending between the superior colliculus and hypothalamus.

Parts of red nucleus

Red nucleus has two parts:

1. **Nucleus magnocellularis,** which is formed by large cells. Fibers from this form the rubrospinal and rubrobulbar tracts.

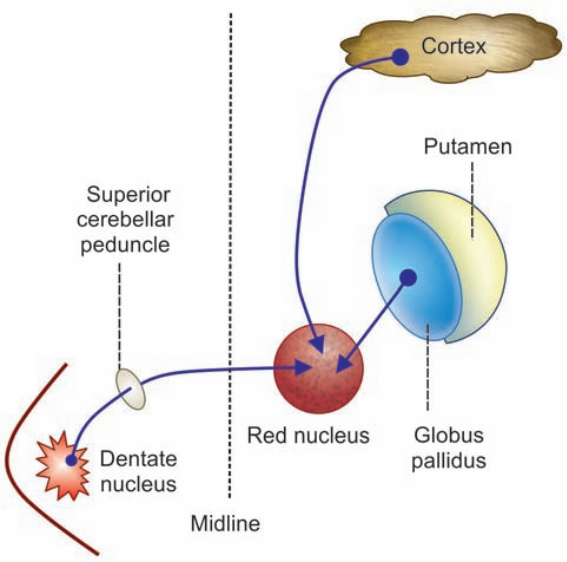

FIGURE 146.1: Afferent connections of red nucleus

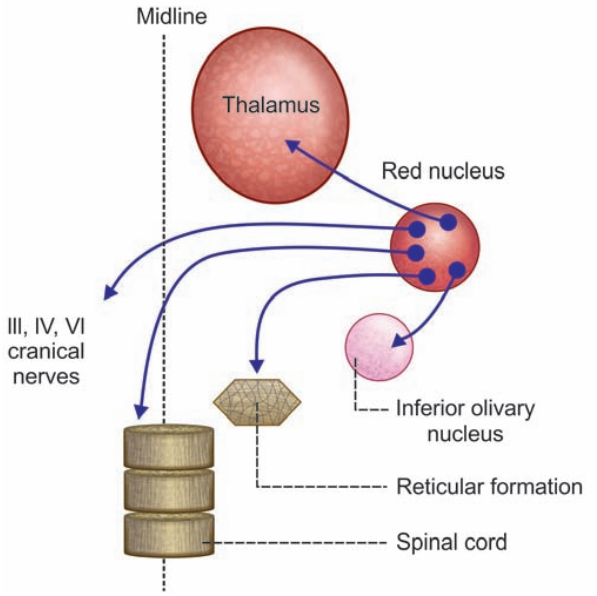

FIGURE 146.2: Efferent connections of red nucleus

2. **Nucleus parvocellularis,** which is formed by smaller cells. Fibers from this form mainly the rubroreticular tract.

Connections of red nucleus

Afferent connections: Red nucleus receives fibers from:

1. Nucleus parvocellularis, which receives fibers from motor cortex (area 6) – corticorubral fibers (Fig. 146.1)
2. Nucleus magnocellularis, which receives fibers from motor cortex (area 6) – pallidorubral fibers
3. Nucleus magnocellularis, which receives fibers from dentate nucleus (of opposite side) – cerebellorubral or dentatorubral tract.

Efferent connections: Red nucleus sends efferent fibers to various parts of brain and spinal cord:

1. Rubrospinal tract to spinal cord (Fig. 146.2)
2. Rubrobulbar tract to medulla
3. Rubroreticular fibers to reticular formation
4. Rubrothalamic tract to lateral ventral nucleus of thalamus
5. Rubro-olivary tract to inferior olivary nucleus
6. Fibers to nuclei of 3rd, 4th and 6th cranial nerves.

Functions of red nucleus

1. *Control of muscle tone:* Because of its connections with cerebellum, vestibular apparatus and skeletal muscle, the red nucleus plays an important role in facilitating the muscle tone.
2. *Control of complex muscular movements:* Red nucleus controls the complex muscular movements. It plays an important role in the integration of various impulses received from many important areas of brain.
3. *Control of righting reflexes:* Red nucleus is the center for all righting reflexes except optical righting reflexes (Chapter 157).
4. *Control of movements of eyeball:* Through its efferent connections with nuclei of 3rd, 4th and 6th cranial nerves, red nucleus plays an important role in the control of ocular movements (Chapter 165).
5. *Control of skilled movements:* Red nucleus plays an important role in controlling the skilled muscular movements by its connections with spinal cord and cerebral cortex.

Thalamus

Chapter 147

- INTRODUCTION
- THALAMIC NUCLEI
  - ANATOMICAL CLASSIFICATION
  - PHYSIOLOGICAL CLASSIFICATION
- CONNECTIONS OF THALAMIC NUCLEI
- THALAMIC RADIATIONS
  - ANTERIOR (FRONTAL) PEDUNCLE OR RADIATION
  - SUPERIOR (CENTROPARIETAL) PEDUNCLE OR RADIATION
  - POSTERIOR (OCCIPITAL) PEDUNCLE OR RADIATION
  - INFERIOR (TEMPORAL) PEDUNCLE OR RADIATION
- FUNCTIONS OF THALAMUS
  - RELAY CENTER
  - CENTER FOR PROCESSING OF SENSORY INFORMATION
  - CENTER FOR DETERMINING QUALITY OF SENSATIONS
  - CENTER FOR SEXUAL SENSATIONS
  - ROLE IN AROUSAL AND ALERTNESS REACTIONS
  - CENTER FOR REFLEX ACTIVITY
  - CENTER FOR INTEGRATION OF MOTOR ACTIVITY
- APPLIED PHYSIOLOGY
  - THALAMIC LESION
  - THALAMIC SYNDROME

INTRODUCTION

Thalamus is a large ovoid mass of gray matter, situated bilaterally in **diencephalon.** Both thalami form 80% of diencephalon. Thalami on both sides are connected in their rostral portions by means of an **intermediate mass.** Caudal portions are more widely separated by corpora quadrigemina.

THALAMIC NUCLEI

Thalamic nuclei are classified by two methods:
A. Anatomical classification
B. Physiological classification.

ANATOMICAL CLASSIFICATION

Thalamus on each side is divided into five main nuclear groups by 'Y'-shaped internal medullary lamina.

1. Midline nuclei
2. Intralaminar nuclei
3. Medial mass of nuclei
4. Lateral mass of nuclei
5. Posterior group of nuclei.

1. *Midline Nuclei*

Midline nuclei are a group of small nuclei, situated on the medial surface of thalamus near the midline (Fig. 147.1).

2. *Intralaminar Nuclei*

Intralaminar nuclei are smaller nuclei present in the medullary septum of thalamus.

3. *Medial Mass of Nuclei*

Medial mass of nuclei are situated medial to septum and it comprises two nuclei:

i. Anterior nucleus
ii. Dorsomedial nucleus.

4. *Lateral Mass of Nuclei*

This group of nuclei are situated lateral to septum. Lateral mass of nuclei are again divided into two subgroups:

i. Dorsal group of lateral mass with two nuclei:
   a. Dorsolateral nucleus
   b. Posterolateral nucleus
ii. Ventral group of lateral mass with three nuclei:
   a. Ventral anterior nucleus
   b. Ventral lateral nucleus
   c. Ventral posterior nucleus. It consists of two parts:
      - Ventral posterolateral nucleus
      - Ventral posteromedial nucleus.

5. *Posterior Group of Nuclei*

Posterior group of nuclei are the continuation of lateral mass of nuclei. It has two subgroups:

i. Pulvinar
ii. Metathalamus which consists of two structures:
   a. Medial geniculate body
   b. Lateral geniculate body.

Thalamic reticular nucleus

Thalamus also includes thalamic reticular nucleus, which is a thin layer of neurons covering the lateral aspect of thalamus. It is separated from thalamus by external medullary lamina. It receives information from reticular formation, cerebral cortex and other thalamic and sends inhibitory signals to other thalamic nuclei.

■ PHYSIOLOGICAL CLASSIFICATION

On the basis of functions and their projections, thalamic nuclei are classified into five groups. This type of classification is also called **Bondok classification.** Five groups of thalamic nuclei are:

1. Specific sensory relay nuclei
2. Specific motor nuclei
3. Association or less specific nuclei
4. Non-specific nuclei
5. Limbic system nuclei.

Nuclei and their functions of each group are given in Table 147.1.

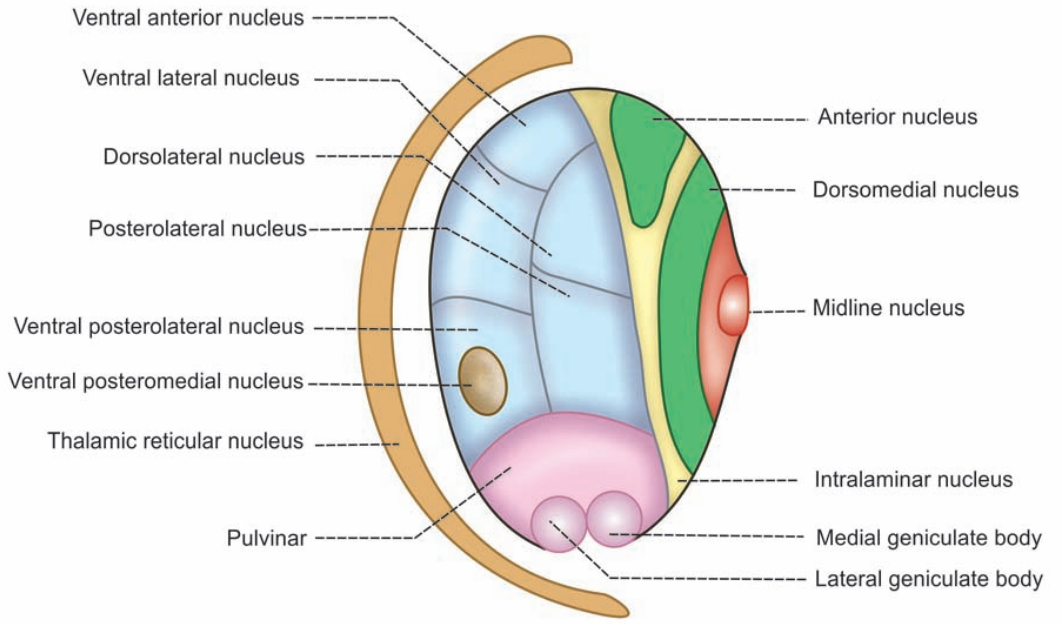

FIGURE 147.1: Thalamic nucleus. Red = Midline nucleus, Yellow = Intralaminar nuclei, Green = Medial mass of nuclei, Blue = Lateral mass of nuclei, Pink = Posterior group of nuclei.

TABLE 147.1: Bondok classification of thalamic nuclei

Group	Nuclei	Functions
1. Specific sensory relay nuclei	i. Ventral posterior nucleus ii. Medical geniculate body iii. Lateral geniculate body	Project sensory signals to distinct (specific) areas of cerebral cortex
2. Specific nuclei	i. Ventral anterior nucleus ii. Ventral lateral nucleus	Receive signals controlling motor activities from cerebellum and corpus striatum and send these signals to motor areas in the cerebral cortex to complete the feedback system of motor control mechanism
3. Association or less specific nuclei	i. Dorsolateral nucleus ii. Posterolateral nucleus iii. Pulvinar	Send information to association areas of cerebral cortex
4. Non-specific nuclei	i. Midline nuclei ii. Intralaminar nuclei iii. Reticular nucleus	Project signals to diffused areas of cerebral cortex
5. Limbic system nuclei	i. Anterior nucleus ii. Dorsolateral nucleus	Project into limbic cortex

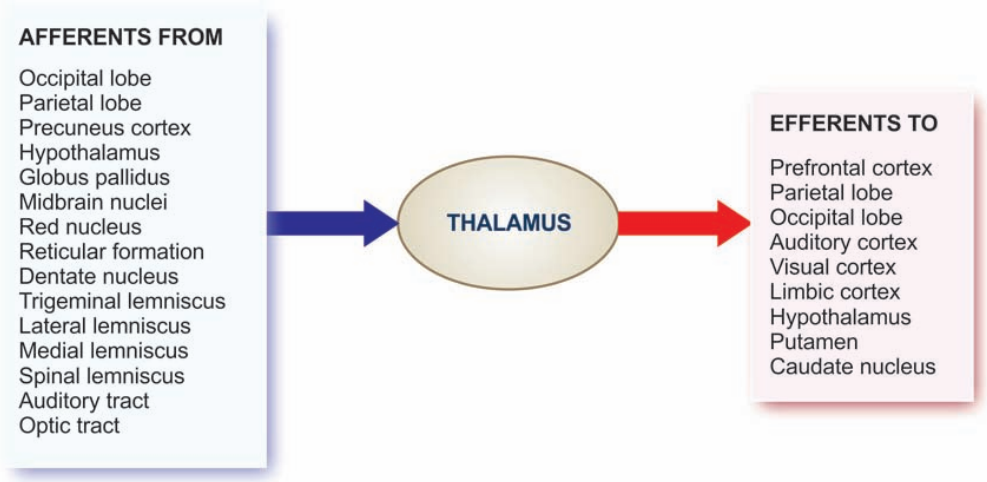

FIGURE 147.2: Connections of thalamus

■ CONNECTIONS OF THALAMIC NUCLEI

Connections of different groups of nuclei are given in Table 147.2 and Figure 147.2.

■ THALAMIC RADIATIONS

Thalamic radiation is the collection of nerve fibers connecting thalamus and cerebral cortex. It contains both thalamocortical and corticothalamic fibers. All these fibers between thalamus and cerebral cortex pass through internal capsule.

Fibers of thalamic radiation are divided into four groups, which are called **thalamic peduncles** or **thalamic stalks.** Thalamic peduncles are:

1. Anterior (frontal) thalamic peduncle or radiation
2. Superior (centroparietal) thalamic peduncle or radiation
3. Posterior (occipital) thalamic peduncle or radiation
4. Inferior (temporal) thalamic peduncle or radiation.

TABLE 147.2: Connections of different nuclear groups of thalamus

Nuclei		Afferent fibers from	Efferent fibers to
1. Midline nuclei		Globus pallidus Hypothalamus Cerebral cortex Midbrain nuclei Reticular formation	Different areas of cerebral cortex
2. Intralaminar nuclei		Reticular formation Trigeminal lemniscus Lateral lemniscus	Cerebral cortex Putamen Caudate nucleus Other thalamic nuclei
3. Medial mass	Anterior nucleus	Mamillary body	Limbic cortex
	Dorsomedial nucleus	Hypothalamus	Limbic cortex Putamen Caudate nucleus Hypothalamus
4. Lateral mass	Dorsolateral nucleus	Precuneus cortex	Precuneus cortex
	Posterolateral nucleus	Parietal lobe	Parietal lobe
	Ventral anterior nucleus	Globus pallidus	Putamen Caudate nucleus Premotor cortex
	Ventral lateral nucleus	Globus pallidus Dentate nucleus Red nucleus	Putamen Caudate nucleus Precentral cortex
	Posterior ventral nucleus	Trigeminal lemniscus Medial lemniscus Spinal lemniscus	Hypothalamus Cerebral cortex – areas 3, 1, 2, 5, 7
5. Posterior group	Pulvinar	Inferior parietal lobe Occipital lobe – areas 18, 19	Inferior parietal lobe Occipital lobe – areas 18, 19
	Medial geniculate body	Auditory tract	Auditory cortex
	Lateral geniculate body	Optic tract	Visual cortex

■ ANTERIOR (FRONTAL) THALAMIC PEDUNCLE OR RADIATION

Anterior thalamic peduncle connects the frontal lobe of cerebral cortex with medial and lateral thalamic nuclei. It contains mostly motor nerve fibers.

■ SUPERIOR (CENTROPARIETAL) THALAMIC PEDUNCLE OR RADIATION

Fibers of this peduncle connect postcentral gyrus (somesthetic area) of parietal lobe and adjacent area in frontal cortex with lateral mass of thalamic nuclei. It contains mainly the sensory fibers.

■ POSTERIOR (OCCIPITAL) THALAMIC PEDUNCLE OR RADIATION

Posterior thalamic peduncle connects occipital lobe of cerebral cortex with pulvinar and lateral geniculate body. It contains the nerve fibers concerned with vision.

■ INFERIOR (TEMPORAL) THALAMIC PEDUNCLE OR RADIATION

Fibers of this peduncle connect temporal lobe and insula with pulvinar and medial geniculate body. This peduncle contains the nerve fibers concerned with hearing.

FUNCTIONS OF THALAMUS

Thalamus is primarily concerned with **somatic functions** and it plays little role in the visceral functions. Following are the various functions of thalamus:

1. RELAY CENTER

Thalamus forms the relay center for the sensations. Impulses of almost all the sensations reach the thalamic nuclei, particularly in the ventral posterolateral nucleus. After being processed in the thalamus, the impulses are carried to cerebral cortex through thalamocortical fibers.

2. CENTER FOR PROCESSING OF SENSORY INFORMATION

Thalamus forms the major center for processing the sensory information. All the peripheral sensory impulses reaching thalamus are integrated and modified before being sent to specific areas of cerebral cortex. This function of thalamus is usually called the processing of sensory information.

Functional Gateway for Cerebral Cortex

Almost all the sensations are processed in thalamus before reaching cerebral cortex. Very little information of somatosensory function is sent directly to cerebral cortex without being processed by the thalamic nuclei. Because of this function, thalamus is usually called 'functional gateway' for cerebral cortex.

3. CENTER FOR DETERMINING QUALITY OF SENSATIONS

Thalamus is also the center for determining the quality of sensations, i.e. to determine the affective nature of sensations. Usually the sensations have two qualities:

i. Discriminative nature
ii. Affective nature.

i. *Discriminative Nature*

Discriminative nature is the ability to recognize the type, location and other details of the sensations and it is the function of cerebral cortex.

ii. *Affective Nature*

Affective nature is the capacity to determine whether a sensation is pleasant or unpleasant and agreeable or disagreeable. Determining the affective nature of sensations is the function of thalamus.

4. CENTER FOR SEXUAL SENSATIONS

Thalamus forms the center for perception of sexual sensations.

5. ROLE IN AROUSAL AND ALERTNESS REACTIONS

Because of its connections with nuclei of reticular formation, thalamus plays an important role in arousal and alertness reactions.

6. CENTER FOR REFLEX ACTIVITY

Since the sensory fibers relay here, thalamus forms the center for many reflex activities.

7. CENTER FOR INTEGRATION OF MOTOR ACTIVITY

Through the connections with cerebellum and basal ganglia, thalamus serves as a center for integration of motor functions.

APPLIED PHYSIOLOGY

THALAMIC LESION

Thalamic lesion occurs mainly because of blockage (due to thrombosis) in thalamogeniculate branch of posterior cerebral artery. Mostly, posteroventral nuclei of thalamus are affected because the thalamogeniculate branch of posterior cerebral artery supplies this part of thalamus. Lesion of thalamus leads to a condition called thalamic syndrome.

THALAMIC SYNDROME

Thalamic syndrome is the neurological disease caused by infarction of posteroventral part of thalamus. It is a rare disease and it has many names. Synonyms of thalamic syndrome are listed in Box 147.1.

BOX 147.1: Synonyms of thalamic syndrome

1. Dejerine-Roussy syndrome
2. Thalamic hyperesthetic anesthesia
3. Thalamic pain syndrome
4. Central pain syndrome
5. Central poststroke pain syndrome
6. Posterior thalamic syndrome
7. Retrolenticular syndrome

In thalamic syndrome, whole body becomes hypersensitive to pain. Effects of thalamic lesion occur in the contralateral (opposite) side.

Following are the symptoms of thalamic syndrome:

1. *Loss of Sensations*

Loss of all sensations **(anesthesia)** occurs as the sensory relay system in thalamus is affected.

2. *Astereognosis*

Astereognosis is the loss of ability to recognize a known object by touch with closed eyes. It is due to the loss of tactile and kinesthetic sensations in thalamic syndrome.

3. *Ataxia*

Ataxia refers to incoordination of voluntary movements. It occurs due to loss of kinesthetic sensation. This type of ataxia due to loss of sensation is called **sensory ataxia.** It is very common in thalamic syndrome.

4. *Thalamic Phantom Limb*

The patient is unable to locate the position of a limb with closed eyes. The patient may search for the limb in air or may have the illusion that the limb is lost. This is called thalamic phantom limb.

5. *Anosognosia*

Anosognosia is the lack of awareness or denial of existance of a neurological defect or general illness or any disability.

6. *Spontaneous Pain and Thalamic Over-reaction*

Spontaneous pain occurs often. Pain stimulus is felt more acutely than in normal conditions **(hyperalgesia).** Pain may be so intense, that it even resists the action of powerful sedatives like morphine. Threshold for pain is very much reduced. Even the light touch may be unpleasant. Sometimes, the patient feels pain even in the absence of pain stimulus. It becomes worst in conditions such as emotional disturbance and exposure to cold or heat. Pain is due to over activity of medial mass of nuclei of thalamus, which escape the lesion.

Abnormal reaction to various stimuli is called thalamic over-reaction.

7. *Involuntary Movements*

Thalamic syndrome is always associated with some involuntary motor movements.

Athetosis

Athetosis means slow writhing and twisting movements.

Chorea

Chorea means quick, jerky, involuntary movements.

Intention tremor

Tremor is defined as rapid alternate rhythmic and involuntary movement of flexion and extension in the joints of fingers and wrist or elbow. Intention tremor is the tremor that develops while attempting to do any voluntary act. Intention tremor is the common feature of thalamic syndrome.

8. *Thalamic Hand or Athetoid Hand*

Athetoid hand is the abnormal attitude of hand in thalamic lesion. It is characterized by moderate flexion at wrist and hyperextension of all fingers.

Internal Capsule

Chapter 148

- DEFINITION
- SITUATION
- DIVISIONS
  - ANTERIOR LIMB
  - POSTERIOR LIMB
  - GENU
  - CAUDAL PORTION
- APPLIED PHYSIOLOGY – EFFECT OF LESIONS
  - IN ANTERIOR LIMB
  - IN POSTERIOR LIMB
  - IN GENU
  - IN CAUDAL PORTION

DEFINITION

Internal capsule is the broad and compact band of afferent and efferent fibers connecting cerebral cortex with brainstem and spinal cord. Cerebral cortex is connected with brainstem and spinal cord by both afferent and efferent fibers. Fibers arising from different parts of cerebral cortex descend down into white matter of cerebral hemispheres in the form of radiating mass of fibers called corona radiata. While passing down towards the brainstem, corona radiata converges in the form of internal capsule.

Fibers from spinal cord and brainstem reach cerebral cortex in the same route. A large portion of internal capsule is formed by thalamic radiation.

SITUATION

Internal capsule is situated in between thalamus and caudate nucleus on the medial side and lenticular nucleus on the lateral side.

DIVISIONS

Internal capsule has two limbs, the anterior and posterior limbs. In between these two limbs, lies the genu of internal capsule. Distal end of posterior limb is continued as the caudal portion of internal capsule (Fig. 148.1). Nerve fibers of each division are given in Table 148.1.

ANTERIOR LIMB

Anterior limb of internal capsule is short and lies between lenticular and caudate nuclei.

POSTERIOR LIMB

Posterior limb is long and situated between thalamus and lenticular nucleus.

GENU

Genu is situated between the anterior and the posterior limbs.

CAUDAL PORTION

Caudal portion is otherwise known as **retrolenticular portion** of internal capsule.

APPLIED PHYSIOLOGY – EFFECT OF LESIONS OF INTERNAL CAPSULE

Lesion of internal capsule is caused by thrombosis or hemorrhage in branches of middle cerebral arteries.

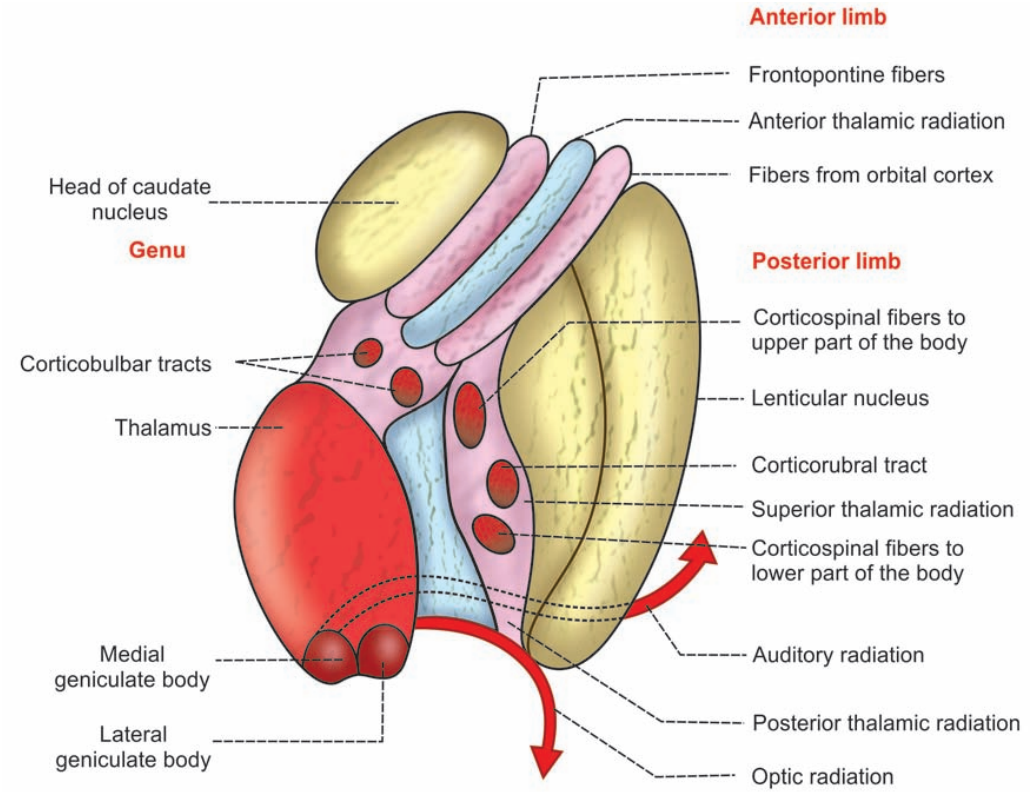

FIGURE 148.1: Components of internal capsule. Pink = Descending fibers, Blue = Ascending fibers.

The effects of lesion depend upon the part of internal capsule involved.

TABLE 148.1: Fibers of internal capsule

Division	Nerve fibers present
1. Anterior limb	1. Anterior thalamic radiation 2. Prefrontal corticopontine (frontopontine) tract 3. Fibers from orbital cortex to hypothalamus
2. Posterior limb	1. Corticospinal tracts 2. Superior thalamic radiation 3. Frontal corticopontine tract
3. Genu	Corticobulbar tract
4. Caudal portion	Posterior thalamic radiation

■ IN ANTERIOR LIMB

Anterior limb contains thalamocortical and frontopontine fibers. Lesion in this limb causes widespread **disability** in the body. Both motor and sensory functions are lost.

■ IN POSTERIOR LIMB

Lesion in posterior limb affects the sensory fibers (thalamocortical fibers). So, it causes:

1. Contralateral **hemianesthesia** (loss of sensation in opposite side of the body)
2. Contralateral **hemihyperesthesia** (abnormal sensation in opposite side of the body)
3. **Hemiplegia** (paralysis of upper and lower limbs in one side of the body).

Hemianesthesia and hemiparesthesia occur because of lesion of superior thalamic radiation. Hemiplegia is due to injury of corticospinal tracts.

■ IN GENU

Lesion in genu causes alteration in **motor activities** in opposite side due to damage of corticobulbar fibers.

■ IN CAUDAL PORTION

Lesion in this portion of internal capsule causes contralateral **hemianesthesia.** It also produces **hemianopia** and **deafness,** because of the involvement of the auditory and visual fibers.

Hypothalamus

Chapter 149

- INTRODUCTION
- NUCLEI
- CONNECTIONS
  - AFFERENT CONNECTIONS
  - EFFERENT CONNECTIONS
- FUNCTIONS
  - SECRETION OF POSTERIOR PITUITARY HORMONES
  - CONTROL OF ANTERIOR PITUITARY
  - CONTROL OF ADRENAL CORTEX
  - CONTROL OF ADRENAL MEDULLA
  - REGULATION OF AUTONOMIC NERVOUS SYSTEM
  - REGULATION OF HEART RATE
  - REGULATION OF BLOOD PRESSURE
  - REGULATION OF BODY TEMPERATURE
  - REGULATION OF HUNGER AND FOOD INTAKE
  - REGULATION OF WATER BALANCE
  - REGULATION OF SLEEP AND WAKEFULNESS
  - ROLE IN BEHAVIOR AND EMOTIONAL CHANGES
  - REGULATION OF SEXUAL FUNCTION
  - ROLE IN RESPONSE TO SMELL
  - ROLE IN CIRCADIAN RHYTHM
- APPLIED PHYSIOLOGY – DISORDERS
  - DIABETES INSIPIDUS
  - DYSTROPHIA ADIPOSOGENITALIS
  - KALLMANN SYNDROME
  - LAURENCE-MOON-BIEDL SYNDROME
  - NARCOLEPSY
  - CATAPLEXY

INTRODUCTION

Hypothalamus is a diencephalic structure. It is situated just below thalamus in the ventral part of **diencephalon.** It is formed by groups of nuclei, scattered in the walls and floor of third ventricle. It extends from optic chiasma to mamillary body.

NUCLEI OF HYPOTHALAMUS

Nuclei of hypothalamus are divided into three groups:

1. Anterior or preoptic group
2. Middle or tuberal group
3. Posterior or mamillary group.

Nuclei of each group are listed in Table 149.1 and represented diagrammatically in Figure 149.1.

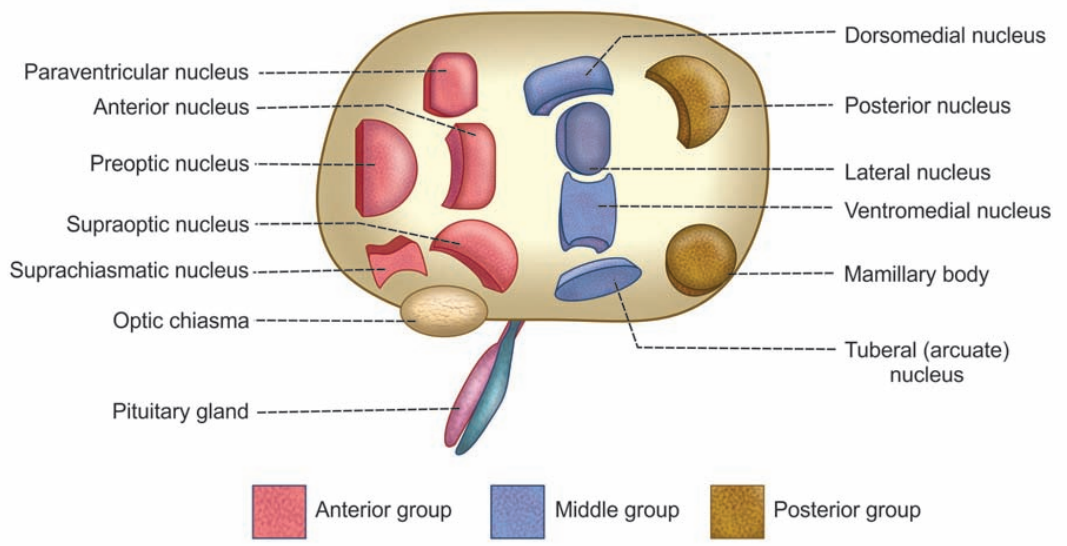

FIGURE 149.1: Nuclei of hypothalamus

TABLE 149.1: Nuclei of hypothalamus

Anterior or Preoptic group	Middle or Tuberal group	Posterior or Mamillary group
1. Preoptic nucleus 2. Paraventricular nucleus 3. Anterior nucleus 4. Supraoptic nucleus 5. Suprachiasmatic nucleus	1. Dorsomedial nucleus 2. Ventromedial nucleus 3. Lateral nucleus 4. Arcuate (tuberal) nucleus	1. Posterior nucleus 2. Mamillary body

CONNECTIONS OF HYPOTHALAMUS

AFFERENT CONNECTIONS TO HYPOTHALAMUS

1. *Medial forebrain bundle:* From rhinencephalon (limbic cortex) to preoptic nucleus, lateral nucleus and mamillary body
2. *Fornix:* From hippocampus to mamillary body
3. *Stria terminalis:* From amygdaloid to preoptic nucleus
4. *Corticohypothalamic fibers:* From prefrontal area (8) and precentral area (6) of cerebral cortex to the supraoptic and paraventricular nuclei of hypothalamus
5. *Pallidohypothalamic fibers:* From globus pallidus to diffused areas of hypothalamus
6. *Thalamohypothalamic fibers:* From dorsomedial and midline nuclei of thalamus to diffused areas of hypothalamus
7. *Reticulohypothalamic fibers:* From reticular formation of brainstem to diffused areas of hypothalamus
8. *Retinohypothalamic fibers:* Fibers from retina to supraoptic, suprachiasmatic and ventromedial nuclei of hypothalamus (Fig. 149.2).

EFFERENT CONNECTIONS FROM HYPOTHALAMUS

1. *Mamillothalamic tract:* From mamillary body to anterior thalamic nuclei
2. *Mamillotegmental tract:* From mamillary body to the tegmental nuclei of midbrain
3. *Periventricular fibers:* Fibers from posterior, supraoptic and tuberal nuclei of hypothalamus pass through periventricular gray matter and reach the following:
   i. Reticular formation in brainstem and spinal cord
   ii. Dorsomedial nucleus of thalamus
   iii. Frontal lobe of cerebral cortex
4. *Hypothalamohypophyseal tract:* From supraoptic and paraventricular nuclei of hypothalamus to posterior pituitary.

FUNCTIONS OF HYPOTHALAMUS

Hypothalamus is the important part of brain, concerned with **homeostasis** of the body. It regulates many vital functions of the body like endocrine functions, visceral functions, metabolic activities, hunger, thirst, sleep, wakefulness, emotion, sexual functions, etc. (Table 149.2).

1. SECRETION OF POSTERIOR PITUITARY HORMONES

Hypothalamus is the site of secretion for the posterior pituitary hormones. **Antidiuretic hormone** (ADH) and **oxytocin** are secreted by supraoptic and paraventricular nuclei. These two hormones are transported by means of axonic or axoplasmic flow through the fibers of hypothalamohypophyseal tracts to posterior pituitary. Refer Chapter 66 for details.

2. CONTROL OF ANTERIOR PITUITARY

Hypothalamus controls the secretions of anterior pituitary gland by secreting **releasing hormones** and **inhibitory hormones.** It secretes seven hormones.

i. Growth hormone-releasing hormone (GHRH)
ii. Growth hormone-releasing polypeptide (GHRP)
iii. Growth hormone-inhibiting hormone (GHIH) or somatostatin
iv. Thyrotropin-releasing hormone (TRH)
v. Corticotropin-releasing hormone (CRH)
vi. Gonadotropin-releasing hormone (GnRH)
vii. Prolactin-inhibiting hormone (PIH).

These hormones are secreted by discrete areas of hypothalamus and transported to anterior pituitary by the **hypothalamohypophyseal portal blood vessels.** Refer Chapter 66 for details.

3. CONTROL OF ADRENAL CORTEX

Anterior pituitary regulates adrenal cortex by secreting **adrenocorticotropic hormone** (ACTH). ACTH secretion is in turn regulated by corticotropin-releasing hormone (CRH), which is secreted by the paraventricular nucleus of hypothalamus (Refer Chapter 70 for details).

4. CONTROL OF ADRENAL MEDULLA

Dorsomedial and posterior hypothamic nuclei are excited by emotional stimuli. These hypothalamic nuclei, in turn, send impulses to adrenal medulla through sympathetic fibers and cause release of **catecholamines,** which are essential to cope up with emotional stress (Chapter 71).

5. REGULATION OF AUTONOMIC NERVOUS SYSTEM

Hypothalamus controls autonomic nervous system (ANS). Sympathetic division of ANS is regulated by posterior and lateral nuclei of hypothalamus. Parasympathetic division of ANS is controlled by anterior group of nuclei. The effects of cerebral cortex on ANS are executed through hypothalamus (Chapter 164).

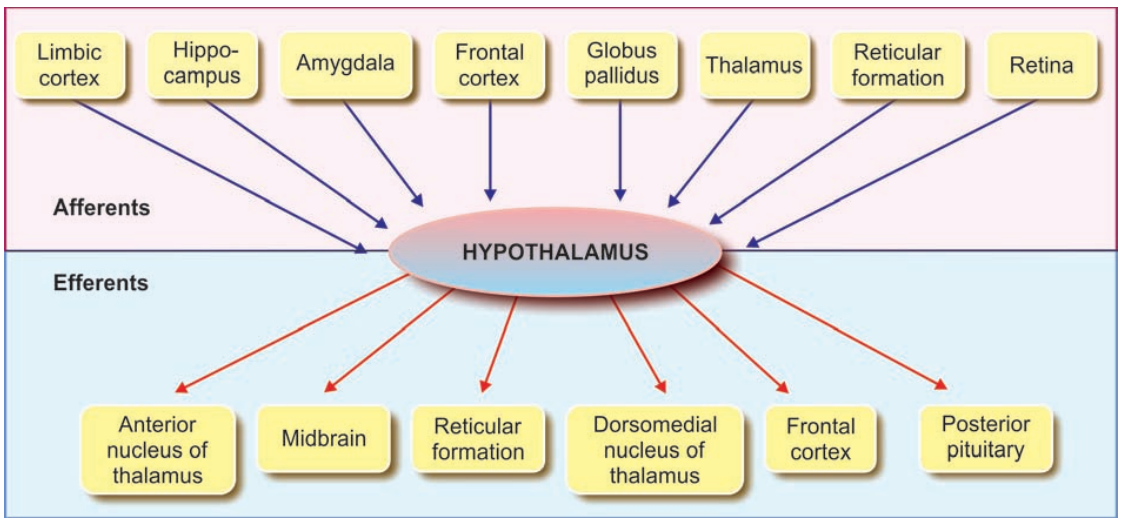

FIGURE 149.2: Connections of hypothalamus

TABLE 149.2: Functions of hypothalamus

Functions	Action/Center	Nuclei/Parts involved
1. Control of anterior pituitary	Releasing hormones Inhibiting hormones	Discrete areas
2. Secretion of posterior pituitary hormones	Oxytocin Antidiuretic hormone (ADH)	Paraventricular nucleus Supraoptic nucleus
3. Control of adrenal cortex	Corticotropin-releasing hormone (CRH)	Paraventricular nucleus
4. Control of adrenal medulla	Catecholamines during emotion	Posterior and dorsomedial nuclei
5. Regulation of autonomic nervous system (ANS)	Sympathetic Parasympathetic	Posterior and lateral nuclei Anterior nuclei
6. Regulation of heart rate	Acceleration Inhibition	Posterior and lateral nuclei Preoptic and anterior nuclei
7. Regulation of blood pressure	Pressor effect Depressor effect	Posterior and lateral nuclei Preoptic area
8. Regulation of body temperature	Heat gain center Heat loss center	Posterior hypothalamus Anterior hypothalamus
9. Regulation of hunger and food intake	Feeding center Satiety center	Lateral nucleus Ventromedial nucleus
10. Regulation of water intake	Thirst center Water retention by ADH	Lateral nucleus Supraoptic nucleus
11. Regulation of sleep and wakefulness	Sleep Wakefulness	Anterior hypothalamus Mamillary body
12. Regulation of behavior and emotion	Reward center Punishment center	Ventromedial nucleus Posterior and lateral nuclei
13. Regulation of sexual function	Sexual cycle	Arcuate and posterior nuclei
14. Regulation of response to smell	Autonomic responses	Posterior hypothalamus
15. Role in circadian rhythm	Rhythmic changes	Suprachiasmatic nucleus

■ 6. REGULATION OF HEART RATE

Hypothalamus regulates heart rate through **vasomotor center** in the medulla oblongata. Stimulation of posterior and lateral nuclei of hypothalamus increases the heart rate. Stimulation of preoptic and anterior nuclei decreases the heart rate (Chapter 101).

■ 7. REGULATION OF BLOOD PRESSURE

Hypothalamus regulates the blood pressure by acting on the **vasomotor center.** Stimulation of posterior and lateral hypothalamic nuclei increases arterial blood pressure and stimulation of preoptic area decreases the blood pressure (Chapter 103).

■ 8. REGULATION OF BODY TEMPERATURE

Body temperature is regulated by hypothalamus, which sets the normal range of body temperature. The set point, under normal physiological conditions is 37°C. Hypothalamus has two centers which regulate the body temperature:

i. **Heat loss center** that is present in preoptic nucleus of anterior hypothalamus
ii. **Heat gain center** that is situated in posterior hypothalamic nucleus.

Regulation of body temperature is explained in Chapter 63.

■ 9. REGULATION OF HUNGER AND FOOD INTAKE

Food intake is regulated by two centers present in hypothalamus:

i. Feeding center
ii. Satiety center.

Feeding Center

Feeding center is in the lateral hypothalamic nucleus. In experimental conditions, stimulation of this center

in animals leads to uncontrolled hunger and increased food intake **(hyperphagia),** resulting in obesity. Destruction of feeding center leads to loss of appetite **(anorexia)** and the animal refuses to take food.

Normally, feeding center is always active. That means, it has the tendency to induce food intake always.

Satiety Center

Satiety center is in the ventromedial nucleus of the hypothalamus. Stimulation of this nucleus in animals causes total loss of appetite and cessation of food intake. Destruction of satiety center leads to **hyperphagia** and the animal becomes obese. This type of obesity is called **hypothalamic obesity.**

Satiety center plays an important role in the regulation of food intake by temporary inhibition of feeding center after food intake.

Mechanism of Regulation of Food Intake

Under normal physiological conditions, appetite and food intake are well balanced and continues in a cyclic manner. Feeding center and satiety center of hypothalamus are responsible for the regulation of appetite and food intake. These centers are regulated by the following mechanisms:

i. Glucostatic mechanism
ii. Lipostatic mechanism
iii. Peptide mechanism
iv. Hormonal mechanism
v. Thermostatic mechanism.

i. *Glucostatic Mechanism*

Cells of satiety center function as **glucostats** or **glucose receptors,** which are stimulated by increased blood glucose level.

While taking food, blood glucose level increases. Slowly the glucostats are stimulated and satiety center is activated. At one stage, it develops the feeling of 'fullness'. Now, the satiety center inhibits the feeding center and stops the food intake.

After few hours of food intake, the blood glucose level decreases and satiety center becomes inactive. So, the feeding center is no longer inhibited. Now it becomes active and increases the appetite and induces food intake. After taking food, once again blood glucose level increases and the cycle is repeated (Fig. 149.3).

However, glucostats do not give response to very high level of glucose in blood **(hyperglycemia).** So, in conditions like diabetes, hyperglycemia fails to stimulate the satiety center. The satiety center does not inhibit the feeding center, so the frequency of food intake increases (polyphagia).

ii. *Lipostatic Mechanism*

Leptin is a peptide secreted by **adipocytes** (cells of adipose tissue). It plays an important role in controlling the food intake and adipose tissue volume. Details of leptin are given in Chapter 73.

When the volume of adipose tissues increases, adipocytes secrete and release a large quantity of leptin into the blood. While circulating through brain, leptin crosses the blood-brain barrier and enters hypothalamus.

In hypothalamus, leptin inhibits the feeding center, resulting in loss of appetite and stoppage of food intake. It is suggested that the cells present in blood-brain barrier contain many receptor-like proteins, which are responsible for the transport of leptin across the barrier.

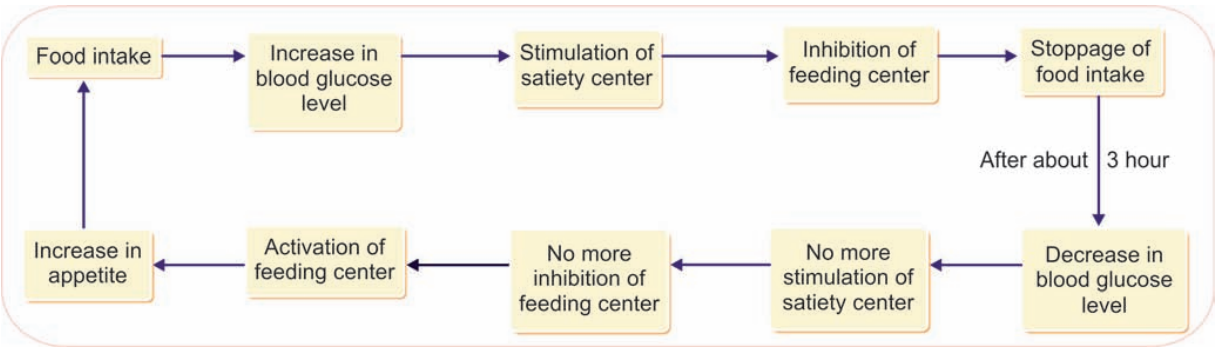
Food intake
Increase in blood glucose level
Stimulation of satiety center
Inhibition of feeding center
Stoppage of food intake
After about 3 hour
Decrease in blood glucose level
No more stimulation of satiety center
No more inhibition of feeding center
Activation of feeding center
Increase in appetite

FIGURE 149.3: Glucostatic mechanism

Mode of action of leptin

Leptin acts through some specific neuropeptides in hypothalamus, such as:

a. Neuropeptide Y: It is secreted in small intestine, medulla and hypothalamus. Normally, this peptide stimulates the food intake. But, leptin inhibits neuropeptide Y, leading to stoppage of food intake. Refer Chapters 44 and 141 for details of neuropeptide Y.
b. *Pro-opiomelanocortin (POMC):* It is secreted from anterior pituitary. It is also secreted from hypothalamus, lungs, GI tract and placenta. Normally, it inhibits food intake. Leptin stimulates the secretion of POMC.

Leptin receptor

Many leptin receptors are identified. However, leptin acts via **'LepRb',** which is the only active receptor present in many nuclei of hypothalamus.

iii. *Peptide Mechanism*

Some peptides regulate the food intake either by stimulating or inhibiting the feeding center, directly or indirectly. The important one among the peptides is ghrelin.

Ghrelin is secreted in stomach (Chapter 44) during fasting. It directly stimulates the feeding center and increases the appetite and food intake. Besides ghrelin, several other peptides are involved in the regulation of food intake.

Peptides, which increase the food intake:

a. Ghrelin
b. Neuropeptide Y.

Peptides, which decrease the food intake:

a. Leptin
b. Peptide YY.

iv. *Hormonal Mechanism*

Some endocrine hormones and GI hormones inhibit the food intake by acting through hypothalamus.

Hormones which inhibit the food intake:

a. Somatostatin
b. Oxytocin
c. Glucagon
d. Pancreatic polypeptide
e. Cholecystokinin.

v. *Thermostatic Mechanism*

Food intake is inversely proportional to body temperature. So in fever, the food intake is decreased. Exact mechanism of this fact is not known. It is suggested that the **preoptic thermoreceptors** (see above) may act via feeding center. The cytokines are also suggested to play a role in decreasing the appetite during fever.

■ 10. REGULATION OF WATER BALANCE

Hypothalamus regulates water content of the body by two mechanisms:

i. Thirst mechanism
ii. Antidiuretic hormone (ADH) mechanism.

i. *Thirst Mechanism*

Thirst center is in the lateral nucleus of hypothalamus. There are some **osmoreceptors** in the areas adjacent to thirst center. When the ECF volume decreases, the osmolality of ECF is increased. If the osmolarity increases by 1% to 2%, the osmoreceptors are stimulated. Osmoreceptors in turn, activate the **thirst center** and thirst sensation is initiated. Now, the person feels thirsty and drinks water. Water intake increases the ECF volume and decreases the osmolality (Fig. 149.4).

ii. *ADH Mechanism*

Simultaneously, when the volume of ECF decreases with increased osmolality, the supraoptic nucleus is stimulated and ADH is released. ADH causes **retention of water** by facultative reabsorption in the renal tubules. It increases the ECF volume and brings the osmolality back to the normal level. On the contrary, when ECF volume is increased, the supraoptic nucleus is not stimulated and ADH is not secreted. In the absence of ADH, more amount of water is excreted through urine and the volume of ECF is brought back to normal.

■ 11. REGULATION OF SLEEP AND WAKEFULNESS

Mamillary body in the posterior hypothalamus is considered as the **wakefulness center.** Stimulation of mamillary body causes wakefulness and its lesion leads to sleep. Stimulation of anterior hypothalamus also leads to sleep.

■ 12. ROLE IN BEHAVIOR AND EMOTIONAL CHANGES

The behavior of animals and human beings is mostly affected by two responding systems in hypothalamus and other structures of limbic system. These two systems act opposite to one another.

The responding systems are concerned with the affective nature of sensations, i.e. whether the sensations

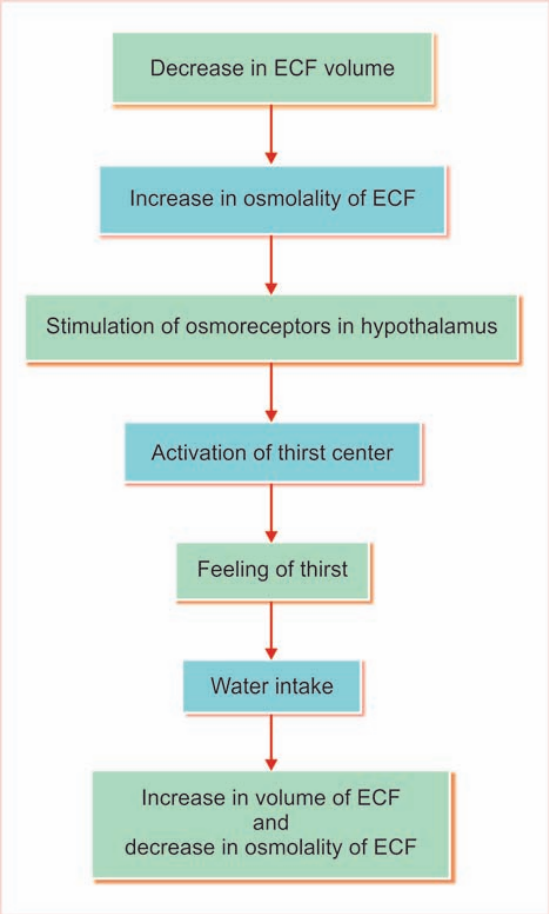

FIGURE 149.4: Thirst mechanism. ECF = Extracellular fluid.

are pleasant or painful. These two qualities are called the reward (satisfaction) and punishment (aversion or avoidance). Hypothalamus has two centers for behavioral and emotional changes. They are:

i. Reward center
ii. Punishment center.

Reward Center

Reward center is situated in medial forebrain bundle and ventromedial nucleus of hypothalamus. Electrical stimulation of these areas in animals pleases or satisfies the animals.

Punishment Center

Punishment center is situated in posterior and lateral nuclei of hypothalamus. Electrical stimulation of these nuclei in animals leads to pain, fear, defense, escape reactions and other elements of punishment.

Role of Reward and Punishment Centers

The importance of the reward and punishment centers lies in the behavioral pattern of the individuals. Almost all the activities of day-to-day life depend upon reward and punishment. While doing something, if the person is rewarded or feels satisfied, he or she continues to do so. If the person feels punished or unpleasant, he or she stops doing so. Thus, these two centers play an important role in the development of the behavioral pattern of a person.

Rage

Rage refers to violent and aggressive emotional expression with extreme anger. It can be developed in animals by stimulating the punishment centers in posterior and lateral hypothalamus. The reactions of rage are expressed by developing a defense posture, which includes:

i. Extension of limbs
ii. Lifting of tail
iii. Hissing and spitting
iv. Piloerection
v. Wide opening of eyeballs
vi. Dilatation of pupil
vii. Severe savage attack even by mild provocation.

Sham Rage

Sham rage means false rage. It is an extreme emotional condition that resembles rage and occurs in some pathological conditions in humans.

In physiological conditions, the animals and human beings maintain a balance between the rage and its opposite state. This balanced condition is called the **calm emotional state.** A major irritation may make a person to loose the temper. However, the minor irritations are usually ignored or overcome. It is because of inhibitory influence of cerebral cortex on hypothalamus. But the calm emotional state is altered during brain lesions. In some cases, even a mild stimulus evokes sham rage. It can occur in decorticated animal also.

Sham rage is due to release of hypothalamus from the inhibitory influence of cortical control.

■ 13. REGULATION OF SEXUAL FUNCTION

In animals, hypothalamus plays an important role in maintaining the sexual functions, especially in females. A decorticate female animal will have regular estrous cycle, provided the hypothalamus is intact. In human beings also, hypothalamus regulates the sexual functions by secreting gonadotropin-releasing

hormones. Arcuate and posterior hypothalamic nuclei are involved in the regulation of sexual functions.

14. ROLE IN RESPONSE TO SMELL

Posterior hypothalamus along with other structures like hippocampus and brainstem nuclei are responsible for the autonomic responses of body to olfactory stimuli. The responses include feeding activities and emotional responses like fear, excitement and pleasure.

15. ROLE IN CIRCADIAN RHYTHM

Circadian rhythm is the regular recurrence of physiological processes or activities, which occur in cycles of 24 hours. It is also called diurnal rhythm. The term circadian is a Latin word, meaning 'around the day'.

Circadian rhythm develops in response to recurring daylight and darkness. The cyclic changes taking place in various physiological processes are set by means of a hypothetical internal clock that is often called **biological clock.**

Suprachiasmatic nucleus of hypothalamus plays an important role in setting the biological clock by its connection with retina via retinohypothalamic fibers. Through the efferent fibers, it sends circadian signals to different parts and maintains the circadian rhythm of sleep, hormonal secretion, thirst, hunger, appetite, etc.

Whenever body is exposed to a new pattern of daylight or darkness rhythm, the biological clock is reset, provided the new pattern is regular. Accordingly, the circadian rhythm also changes.

APPLIED PHYSIOLOGY – DISORDERS OF HYPOTHALAMUS

The lesion of hypothalamus occurs due to tumors, encephalitis and ischemia. Following features develop in hypothalamic lesion:

1. Disturbances in carbohydrate and fat metabolisms, when lateral, arcuate and ventromedial nuclei are involved in lesion
2. Disturbance in sleep due to lesion in mamillary body and anterior hypothalamus
3. Disturbance in sympathetic or parasympathetic function occurs due to lesion in posterior, lateral and anterior nuclei
4. Emotional manifestations, leading to sham rage due to lesion in ventromedial and posterolateral parts
5. Disturbance in sexual functions due to the lesion in midhypothalamus.

One or more of the above features can become prominent, resulting in some clinical manifestations such as:

1. Diabetes insipidus
2. Dystrophia adiposogenitalis
3. Kallmann syndrome
4. Laurence-Moon-Biedl syndrome
5. Narcolepsy
6. Cataplexy.

DIABETES INSIPIDUS

Diabetes insipidus is the condition characterized by excretion of large quantity of water through urine. Refer Chapter 66 for details.

DYSTROPHIA ADIPOSOGENITALIS

This condition is characterized by obesity and sexual infantilism, associated with dwarfism (if the condition occurs during growing period). It is also called **Fröhlich syndrome.** Refer Chapter 66 for details.

KALLMANN SYNDROME

Kallmann syndrome is a genetic disorder characterized by hypogonadism, associated with **anosmia** (loss of olfactory sensation) or **hyposmia** (decreased olfactory sensation). It is also called **hypogonadotropic hypogonadism,** since it occurs due to deficiency of gonadotropin-releasing hormones, secreted by hypothalamus. Refer Chapter 66 for details.

LAURENCE-MOON-BIEDL SYNDROME

This disorder of hypothalamus is characterized by moon face (facial contours become round by hiding the bony structures), obesity, **polydactylism** (having one or more extra fingers or toes), mental retardation and hypogenitalism.

NARCOLEPSY

Narcolepsy is a hypothalamic disorder with abnormal sleep pattern. There is a sudden attack of uncontrollable desire for sleep and the person suddenly falls asleep. It occurs in the daytime.

The sleep may resemble the normal sleep. The duration of sleep is very short. It may be from few seconds to 20 minutes. In night, sleep may be normal but is often disturbed or there may be insomnia (loss of sleep).

CATAPLEXY

Cataplexy is the sudden uncontrolled outbursts of emotion associated with narcolepsy. Due to emotional outburst like anger, fear or excitement, the person becomes completely exhausted with muscular weakness. The attack is brief and last for few seconds to a few minutes. Consciousness is not lost.

Cerebellum

Chapter 150

- PARTS
  - VERMIS
  - CEREBELLAR HEMISPHERES
- DIVISIONS
  - ANATOMICAL DIVISIONS
  - PHYLOGENETIC DIVISIONS
  - FUNCTIONAL DIVISIONS
- FUNCTIONAL ANATOMY
  - GRAY MATTER
  - CEREBELLAR NUCLEI
  - WHITE MATTER
- VESTIBULOCEREBELLUM
  - COMPONENTS
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- APPLIED PHYSIOLOGY – CEREBELLAR LESIONS
  - DISTURBANCES IN TONE AND POSTURE
  - DISTURBANCES IN EQUILIBRIUM
  - DISTURBANCES IN MOVEMENTS

PARTS OF CEREBELLUM

Cerebellum consists of a narrow, worm-like central body called **vermis** and two lateral lobes, the right and left **cerebellar hemispheres** (Fig. 150.1).

VERMIS

Vermis of cerebellum is formed by nine parts. Part of vermis on the upper surface of cerebellum is known as **superior vermis** and the part on lower surface of cerebellum is called **inferior vermis.**

Parts of superior vermis and inferior vermis are listed in Table 150.1.

Nodulus is continued on either side as an elongated and somewhat lobulated structure called flocculus. Nodulus and **flocculi** are together called **flocculonodular lobe.** On either side of pyramid, there is another extension named paraflocculus.

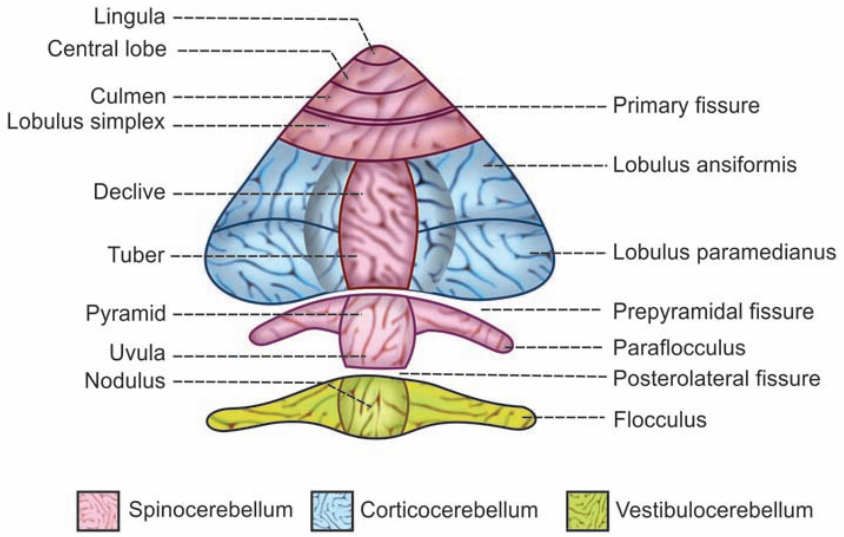

FIGURE 150.1: Parts and functional divisions of cerebellum

TABLE 150.1: Parts of superior and inferior vermis

Superior vermis	Inferior vermis
1. Lingula	6. Tuber
2. Central lobe	7. Pyramid
3. Culmen	8. Uvula
4. Lobulus simplex	9. Nodulus
5. Declive	

Fissures Present Over the Surface of Vermis

1. Primary fissure between culmen and lobulus simplex
2. Prepyramidal fissure between tuber and pyramid
3. Posterolateral fissure between uvula and nodulus.

■ CEREBELLAR HEMISPHERES

Cerebellar hemispheres are the extended portions on either side of vermis.

Each hemisphere has two portions:

1. **Lobulus ansiformis** or **ansiform lobe,** which is the larger portion of cerebellar hemisphere
2. **Lobulus paramedianus** or **paramedian lobe,** which is the smaller portion of cerebellar hemisphere.

■ DIVISIONS OF CEREBELLUM

Division of cerebellum into different major parts is done by three methods:

A. Anatomical divisions
B. Phylogenetic divisions
C. Physiological or functional divisions.

■ ANATOMICAL DIVISIONS

On structural basis, the whole cerebellum is divided into three portions:

1. Anterior lobe
2. Posterior lobe
3. Flocculonodular lobe.

1. *Anterior Lobe*

Anterior lobe includes lingula, central lobe and culmen. It is separated from posterior lobe by primary fissure.

2. *Posterior Lobe*

Posterior lobe consists of lobulus simplex, declive, tuber, pyramid, uvula, paraflocculi and the two portions of hemispheres, viz. ansiform lobe and paramedian lobe.

3. *Flocculonodular Lobe*

Flocculonodular lobe includes nodulus and the lateral extension on either side called flocculus. It is separated from rest of the cerebellum by posterolateral fissure.

■ PHYLOGENETIC DIVISIONS

Depending upon phylogeny, the cerebellum is divided into two divisions:

1. Paleocerebellum
2. Neocerebellum.

1. *Paleocerebellum*

Paleocerebellum is the phylogenetically oldest part of cerebellum. It includes two divisions:

i. **Archicerebellum,** which includes flocculo-nodular lobe
ii. **Paleocerebellum proper,** which includes lingula, central lobe, culmen, lobulus simplex, pyramid, uvula and paraflocculi.

2. *Neocerebellum*

Neocerebellum is the phylogenetically newer portion of cerebellum. It includes declive, tuber and the two portions of cerebellar hemispheres, viz. lobulus ansiformis and lobulus paramedianus.

■ PHYSIOLOGICAL OR FUNCTIONAL DIVISIONS

Based on functions, the cerebellum is divided into three divisions:

1. Vestibulocerebellum
2. Spinocerebellum
3. Corticocerebellum.

1. *Vestibulocerebellum*

Vestibulocerebellum includes flocculonodular lobe that forms the archicerebellum.

2. *Spinocerebellum*

Spinocerebellum includes lingula, central lobe, culmen, lobulus simplex, declive, tuber, pyramid, uvula and paraflocculi and medial portions of lobulus ansiformis and lobulus paramedianus.

3. *Corticocerebellum*

Corticocerebellum includes lateral portions of lobulus ansiformis and lobulus paramedianus.

■ FUNCTIONAL ANATOMY OF CEREBELLUM

Cerebellum is made up of outer gray matter or **cerebellar cortex** and an inner **white matter.** White matter is formed by afferent and efferent nerve fibers of cerebellum. Gray masses called **cerebellar nuclei** are located within the white matter.

■ GRAY MATTER

Gray matter or cerebellar cortex is made up of structures arranged in three layers (Fig. 150.2). Each layer of gray matter is uniform in structure and thickness, throughout the cerebellum.

Layers of gray matter:

1. Outer molecular or plexiform layer
2. Intermediate Purkinje layer
3. Inner granular layer.

1. *Molecular or Plexiform Layer*

Molecular or plexiform layer is the outermost layer of cortex having the cells arranged in two strata. Superficial stratum contains few star-shaped cells known as **stellate cells.** Deep stratum contains **basket cells.** In addition to stellate and basket cells, the molecular layer contains the following structures:

i. **Parallel fibers,** which are the axons of granule cells, present in granular layer
ii. Terminal portions of **climbing fibers** (afferents from medulla)
iii. Dendrites of **Purkinje cells** and **Golgi cells.**

Cell junctions in molecular layer

Molecular layer contains the following cellular junctions:

i. Dendrites of stellate cells and basket cells synapse with parallel fibers, which are the axons of granule cells
ii. Axons of stellate cells end on the dendrites of Purkinje cells. However, the axon of basket cell descends down into the Purkinje layer and forms the transverse fiber, that ends on the soma of Purkinje cells.
iii. Dendrites of Purkinje cells synapse with climbing fibers and parallel fibers
iv. Dendrites of Golgi cells situated in inner granular layer enter the molecular layer and end on parallel fibers.

2. *Purkinje Layer*

Purkinje layer is situated in between outer molecular layer and inner granular layer. It is the thinnest layer, having a single layer of flask-shaped **Purkinje cells.** Purkinje cells are the largest neurons in the body. Dendrites of these cells ascend through the entire thickness of molecular layer and arborize there. These dendrites terminate either on climbing fibers or the parallel fibers. Axons of the basket cells form the transverse fibers, which descend down and end on the soma of Purkinje cells. Axons of Purkinje cells descend into the white matter and terminate on the cerebellar nuclei and vestibular nuclei via cerebellovestibular tract.

Purkinje cells are termed as **'final common path' of cerebellar cortex.** It is because the impulses from

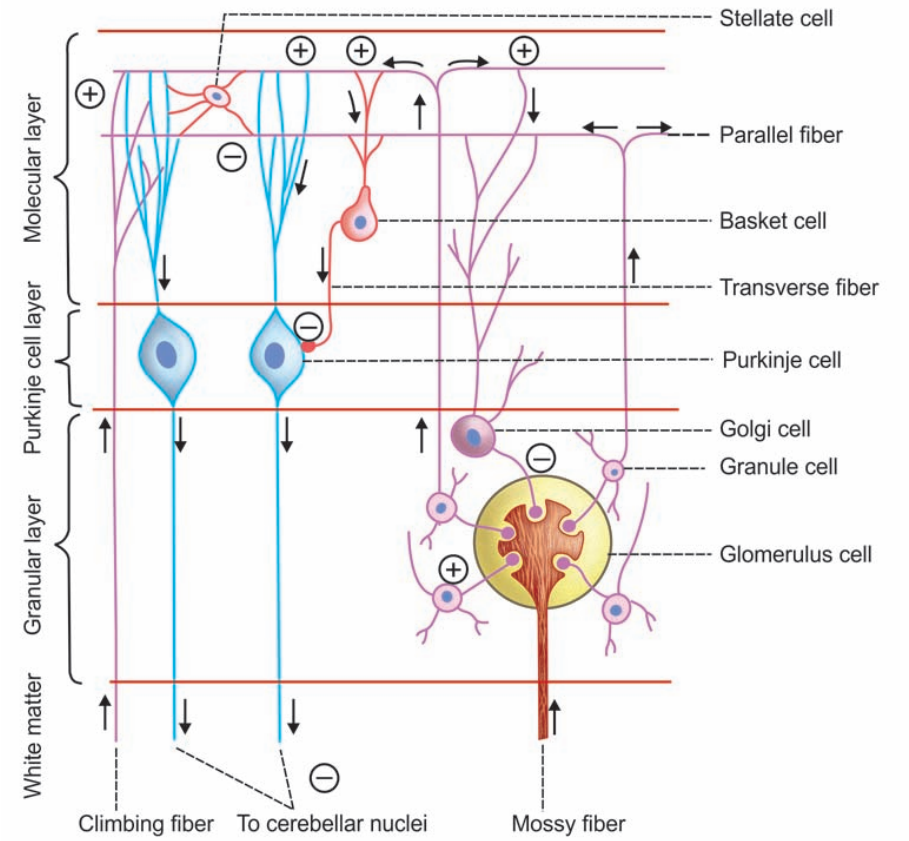

FIGURE 150.2: Structure of cerebellar cortex. (+) = Excitation, (–) = Inhibition.

different parts of cerebellar cortex are transmitted to other parts of brain only through Purkinje cells.

3. *Granular Layer*

Granular layer is the innermost layer of cerebellar gray matter and it is in between Purkinje layer and the cerebellar white matter. It is formed by interneurons called **granule cells** and **Golgi cells.** Total number of interneurons in this layer is about half the number of all neurons in the whole nervous system.

Axon of granule cell ascends into molecular layer and forms the parallel fiber, which synapses with dendrites of Purkinje cells, stellate cells, basket cells and Golgi cells. Dendrites of granule cells and the axon and few dendrites of a Golgi cell synapse with **Mossy fiber.** The synaptic area of these cells is called **glomerulus** and it is encapsulated by the processes of **glial cells.**

Afferent Fibers to Cerebellar Cortex

Cerebellar cortex receives afferent signals from other parts of brain through two types of nerve fibers:

1. Climbing fibers
2. Mossy fibers.

1. *Climbing fibers*

Climbing fibers arise from the neurons of inferior olivary nucleus, situated in medulla and reach the cerebellum via **olivocerebellar tract. Inferior olivary nucleus** relays the output signals from motor areas of cerebral cortex and the proprioceptive signals from different parts of the body to the cerebellar cortex via climbing fibers. Proprioceptive impulses from different parts of the body reach the inferior olivary nucleus through spinal cord and vestibular system.

After reaching the cerebellum, the climbing fibers ascend into molecular layer and terminate on the dendrites of Purkinje cells. While passing through cerebellum, climbing fibers of olivocerebellar tract send collaterals to cerebellar nuclei. So, impulses from cerebral cortex and proprioceptors of the body are conveyed not only to cerebellar cortex, but also to the cerebellar nuclei through the climbing fibers. Each climbing fiber innervates one single Purkinje cell.

2. *Mossy fibers*

Unlike climbing fibers, the mossy fibers have many sources of origin, namely motor areas of cerebral cortex, pons, medulla and spinal cord. Fibers arising from all these areas send collaterals to cerebellar nuclei before reaching the cerebellar cortex. So, like climbing fibers, mossy fibers also convey afferent impulses to both cerebellar nuclei and cerebellar cortex. Some of the mossy fibers arise from cerebellar nuclei.

Mossy fibers reach the granular layer of cerebellar cortex and divide into many terminals. Each terminal enters a specialized structure called glomerulus and ends in a large expanded structure that forms the central portion of the glomerulus. Dendrites of granule cells and axon and dendrites of Golgi cells synapse on the mossy fiber giving a thick bushy appearance. The word **'mossy'** refers to the appearance of a plant called **moss,** which grows into dense clumps and hence, these fibers are called mossy fibers.

Neuronal Activity in Cerebellar Cortex and Nuclei

Functions of cerebellum are executed mainly by the impulses discharged from cerebellar nuclei. However, cerebellar cortex controls the discharge from nuclei constantly via the fibers of Purkinje cells. It is done in accordance with the signals received by cerebellar cortex from different parts of the brain and body via climbing and mossy fibers.

Entire process involves a series of neuronal activity:

1. Climbing fibers excite the Purkinje cells directly and cerebellar nuclei via collaterals, by releasing **aspartate.** Excitatory effect of climbing fiber on Purkinje cell is very strong because each climbing fiber ends on a single Purkinje cell (Table 150.2).
2. Mossy fibers excite the Purkinje cells indirectly. In the glomeruli, mossy fibers release glutamate and excite the granule cells and Golgi cells. Collaterals of mossy fibers activate the cerebellar nuclei also by **glutamate.**
3. Granule cells, which are activated by mossy fibers in turn, excite the Purkinje cells, stellate cells and the basket cells through the parallel fibers.

   Neurotransmitter utilized by granule cells is **glutamate** or **aspartate.** Granule cells are the only excitatory cells in cerebellar cortex, while all other cells are inhibitory in function. Each mossy fiber innervates many Purkinje cells indirectly via granule cells. So, the excitatory effect of mossy fibers on Purkinje cells is weak.
4. Stellate cells and basket cells, which are activated by granule cells, inhibit the Purkinje cells by releasing GABA. This type of inhibition is called feed forward inhibition (Chapter 140).
5. Golgi cell that is activated by mossy fibers, in turn, provides feedback inhibition to granule cells by releasing **GABA,** i.e. it inhibits the transmission of impulse from mossy fiber to granule cell
6. Cerebellar nuclei are excited by collaterals from climbing and mossy fibers. In turn, the nuclei send excitatory impulses to thalamus and different nuclei in brainstem.
7. However, signals discharged from Purkinje cells inhibit cerebellar nuclei via GABA. Purkinje cells

TABLE 150.2: Interneuronal activity in cerebellum

Neuron	Action on	Action	Neurotransmitter
Climbing fibers	Purkinje cells and Cerebellar nuclei	Excitation	Aspartate
Mossy fibers	Granule cells Golgi cells and Cerebellar nuclei	Excitation	Glutamate
Granule cells	Purkinje cells Stellate cells Basket cells	Excitation	Glutamate/Aspartate
Stellate cells	Purkinje cells	Inhibition	GABA
Basket cells	Purkinje cells	Inhibition	GABA
Golgi cells	Granule cells	Inhibition	GABA
Purkinje cells	Cerebellar nuclei Vestibular nuclei	Inhibition	GABA

GABA = Gamma aminobutyric acid

inhibit the activities of vestibular nuclei also. Thus, it is clear that the cerebellar cortex plays an important role in modulating the excitatory signals of following pathways:

i. From cerebellar nuclei to cerebral cortex via thalamus
ii. From final common motor pathway via brainstem and spinal cord.

Because of this activity of cerebellar cortex, movements of body are well organized and coordinated.

■ CEREBELLAR NUCLEI

Cerebellar nuclei are the masses of gray matter scattered in the white matter of cerebellum. There are four nuclei on either side (Fig. 150.3).

1. *Fastigial Nucleus*

Fastigial nucleus is also known as **nucleus fastigi.** Phylogenetically, it is the oldest cerebellar nucleus. It is placed near the midline on the roof of IV ventricle.

2. *Globosus Nucleus*

Globosus nucleus is situated lateral to nucleus fastigi. This is also known as **nucleus globosus.**

3. *Emboliform Nucleus*

Emboliform nucleus is also called **nucleus emboliformis.** This nucleus is below the nucleus fastigi and nucleus globosus.

4. *Dentate Nucleus*

Dentate nucleus is also called **nucleus dentatus.** It is the largest cerebellar nucleus. As it is crenated, it is called dentate nucleus. It is situated lateral to all the other nuclei.

■ WHITE MATTER OF CEREBELLUM

White matter of cerebellum is formed by afferent and efferent nerve fibers. These nerve fibers are classified into three groups.

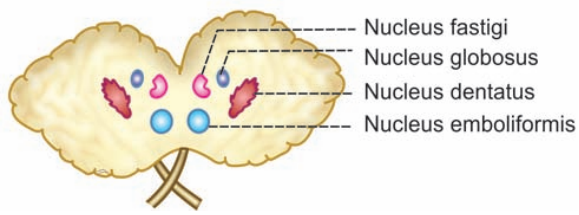

FIGURE 150.3: Cerebellar nuclei

1. *Association fibers*

Association fibers connect different regions of same cerebellar hemisphere.

2. *Commissural fibers*

Commissural fibers connect the areas of both halves of cerebellar cortex.

3. *Projection fibers*

Projection fibers are the afferent and efferent nerve fibers which connect cerebellum with other parts of central nervous system. Projection fibers of cerebellum are arranged in three bundles (Fig. 150.4):

i. Inferior cerebellar peduncles between cerebellum and medulla oblongata
ii. Middle cerebellar peduncles between cerebellum and pons
iii. Superior cerebellar peduncles between cerebellum and midbrain.

i. *Inferior Peduncles*

Inferior cerebellar peduncles are otherwise called **restiform bodies** and contain predominantly afferent fibers. These nerve fibers transmit the impulses from tactile receptors, proprioceptors and receptors in vestibular apparatus to cerebellum.

ii. *Middle Peduncles*

Middle cerebellar peduncles are otherwise called **brachia pontis.** These penduncles contain predominantly, the afferent fibers. Most of the fibers of the middle cerebellar peduncles are commissural fibers, which connect the areas of both the halves of cerebellar cortex.

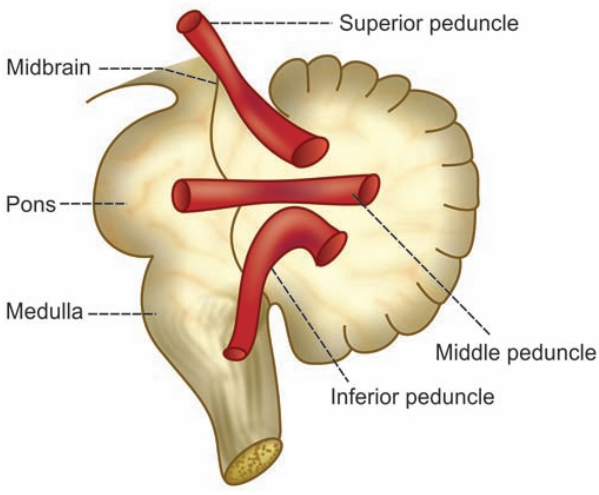

FIGURE 150.4: Cerebellar peduncles

iii. *Superior Peduncles*

Superior cerebellar peduncles are otherwise called the **brachia conjunctivae** and contain predominantly, efferent fibers.

■ VESTIBULOCEREBELLUM (ARCHICEREBELLUM)

Vestibulocerebellum is connected with the **vestibular apparatus** and so it is known as vestibulocerebellum. Since vestibulocerebellum is the phylogenetically oldest part of cerebellum, it is also called **archicerebellum.** It is concerned with the maintenance of posture and equilibrium.

■ COMPONENTS

Vestibulocerebellum includes the **flocculonodular lobe** that is formed by the **nodulus** of vermis and its lateral extensions called **flocculi** (Fig. 150.1 and Table 150.3).

Uvula of vermis is also considered as the part of vestibulocerebellum by some physiologists.

■ CONNECTIONS

Afferent Connections

Vestibulocerebellar tract

Vestibulocerebellar tract is formed by the fibers arising from the vestibular nuclei, situated in pons and medulla. It passes through the inferior cerebellar peduncle of the same side and reaches the cerebellar nuclei, nucleus globosus, nucleus emboliformis and nucleus fastigi (Fig. 150.5). Fibers from these nuclei, reach the vestibulocerebellum (flocculonodular node).

Vestibular nuclei in turn, receive fibers from vestibular apparatus situated in the inner ear, through vestibular division of cochlear (VIII cranial) nerve.

Efferent Connections

1. *Cerebellovestibular tract*

Fibers of cerebellovestibular tract arise from the flocculonodular lobe, pass through the inferior cerebellar peduncle of the same side and terminate on the vestibular nuclei in brainstem.

Fibers from vestibular nuclei form medial and lateral vestibulospinal tracts, which terminate on the medial group of alpha motor neurons in the spinal cord. This pathway forms the part of medial system of motor pathway (extrapyramidal system).

2. *Fastigiobulbar tract*

Fibers of fastigiobulbar tract arise from fastigial nucleus, pass through inferior cerebellar peduncle of the same side and terminate on vestibular nuclei and reticular formation in medulla oblongata.

From vestibular nuclei, vestibulospinal tracts (mentioned above) arise and terminate on alpha motor neurons. From reticular formation, reticulospinal tract arises and terminates on gamma motor neurons in the spinal cord forming the part of medial motor system (extrapyramidal system).

TABLE 150.3: Components and connections of functional divisions of cerebellum

Division	Components	Afferent connections	Efferent connections
Vestibulocerebellum	Flocculonodular lobe (nodulus and flocculi)	Vestibulocerebellar tract	1. Cerebellovestibular tract 2. Fastigiobulbar tract
Spinocerebellum	Lingula Central lobe Culmen Lobulus simplex Declive Tuber Pyramid Uvula Paraflocculi and Medial portions of cerebral hemispheres	1. Dorsal spinocerebellar tract 2. Ventral spinocerebellar tract 3. Cuneocerebellar tract 4. Olivocerebellar tract 5. Pontocerebellar tract 6. Tectocerebellar tract 7. Trigeminocerebellar tract	1. Fastigiobulbar tract 2. Cerebelloreticular tract 3. Cerebello-olivary tract
Corticocerebellum	Lateral portions of cerebral hemispheres	1. Pontocerebellar tract 2. Olivocerebellar tract	1. Dentatothalamic tract 2. Dentatorubral tract

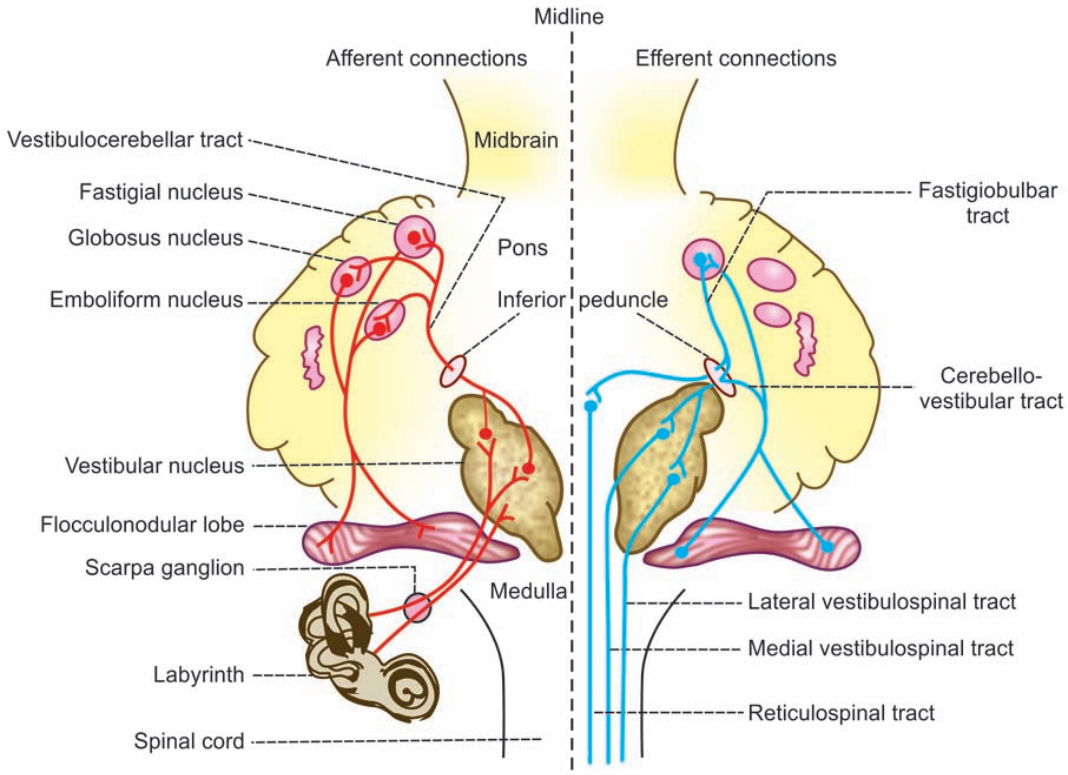

FIGURE 150.5: Connections of vestibulocerebellum. Red = Affernt connections, Blue = Efferent connections.

■ FUNCTIONS

Vestibulocerebellum regulates **tone, posture** and **equilibrium** by receiving impulses from vestibular apparatus. Vestibular apparatus sends information regarding gravity, linear movement and angular acceleration to vestibulocerebellum through vestibulocerebellar tract. Vestibulocerebellum, in turn, sends signals to spinal cord via vestibulospinal and reticulospinal tracts.

Mechanism of Action of Vestibulocerebellum

Normally, vestibular nuclei **facilitate the movements** of trunk, neck and limbs through vestibulospinal tracts and alpha motor neurons. Medullary reticular formation **inhibits the muscle tone** through reticulospinal tract and gamma motor neurons.

However, vestibulocerebellum inhibits both vestibular nuclei and medullary reticular formation. As a result, the **movements** of neck, trunk and limbs are **checked** and the **muscle tone increases.** Because of these effects, any disturbance in posture and equilibrium is corrected.

In the lesion of vestibulocerebellum, there is a reduction in muscle tone (hypotonia) and failure to maintain posture and equilibrium.

■ SPINOCEREBELLUM (PALEOCEREBELLUM)

Spinocerebellum is connected with spinal cord and hence the name. It forms the major **receiving area** of cerebellum for sensory inputs. It is concerned with the maintenance of muscle tone and anticipatory adjustment of muscle contraction during movement. Spinocerebellum is also phylogenetically older part of cerebellum. It is otherwise called **paleocerebellum.**

■ COMPONENTS

Spinocerebellum consists of medial portions of **cerebellar hemisphere,** paraflocculi and the parts of vermis, viz. lingula, central lobe, culmen, lobulus simplex, declive, tuber, pyramid and uvula (Fig. 150.1 and Table 150.3). However, some physiologists do not consider uvula as a part of spinocerebellum.

■ CONNECTIONS

Afferent Connections

1. Dorsal spinocerebellar tract

Dorsal spinocerebellar tract arises from Clarke's column of cells in the dorsal gray horn of spinal cord. It is uncrossed tract and reaches the spinocerebellum through the inferior peduncle of same side (Fig. 150.6). This tract conveys the proprioceptive information from the limbs of same side regarding the position and movements.

2. *Ventral spinocerebellar tract*

Fibers of ventral spinocerebellar tract arise from the marginal cells in the dorsal gray horn of spinal cord. After taking the origin, the fibers cross the midline, ascend in the opposite side and reach the spinocerebellum through superior cerebellar peduncle. This tract conveys the information about the position and movements of opposite limbs to spinocerebellum.

3. *Cuneocerebellar tract*

Cuneocerebellar tract arises from accessory cuneate nucleus, situated lateral to cuneate nucleus in medulla. It reaches the spinocerebellum through the inferior cerebellar peduncle of the same side. This tract conveys the proprioceptive impulses from upper limb, upper trunk and neck to spinocerebellum.

4. *Olivocerebellar tract*

Olivocerebellar tract is formed by climbing fibers arising from the inferior olivary nucleus in medulla. After taking origin, these fibers cross the midline and reach

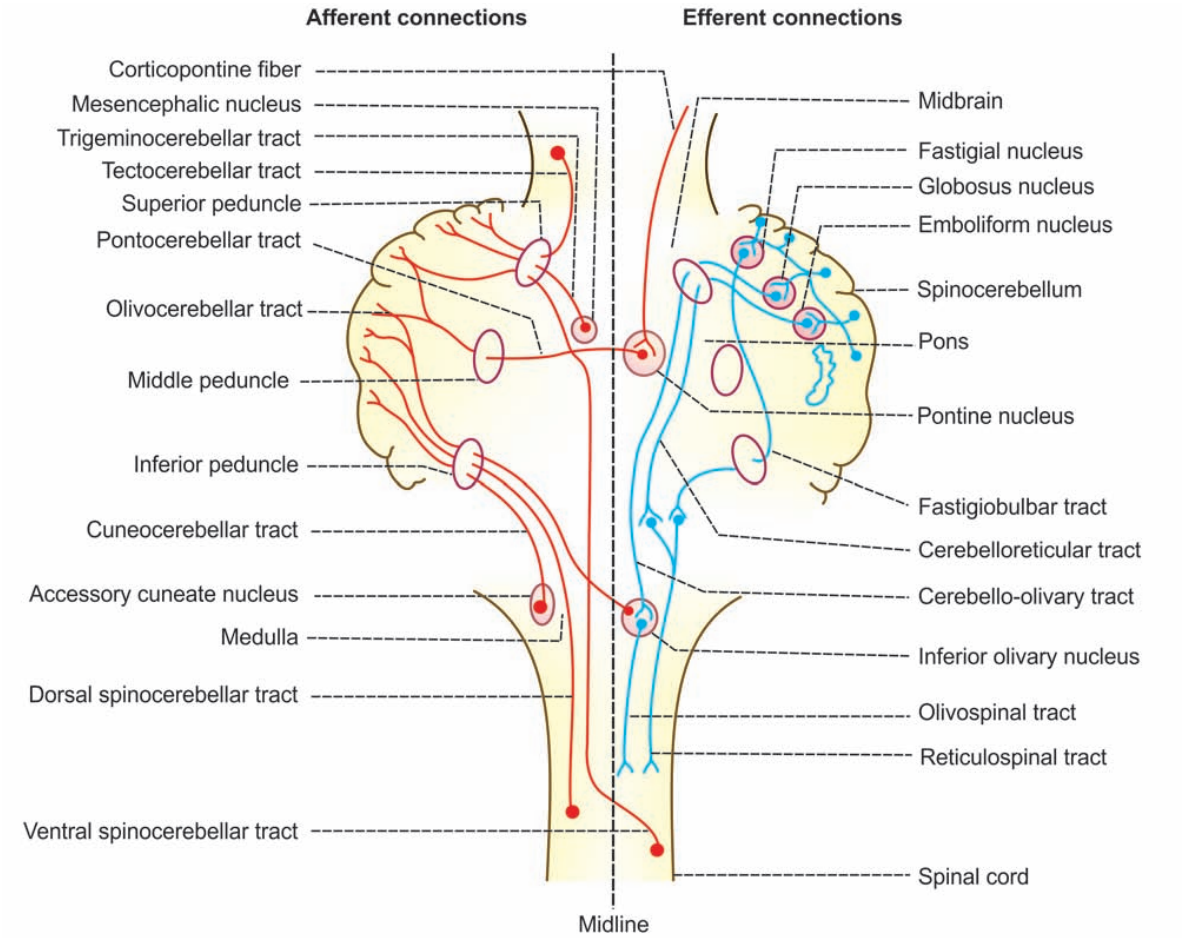

FIGURE 150.6: Connections of spinocerebellum. Red = Afferent connections, Blue = Efferent connections.

the spinocerebellum through the inferior cerebellar peduncle of the opposite side. This tract also gives collaterals to cerebellar nuclei, particularly the globosus nucleus and emboliform nucleus. Inferior olivary nucleus receives afferent fibers from three sources:

i. Brainstem nuclei of same side
ii. Spinal cord through spino-olivary tract of same side
iii. Cerebral cortex of opposite side.

Olivocerebellar tract conveys proprioceptive impulses from the body and output signals from cerebral cortex to spinocerebellum.

5. *Pontocerebellar tract*

Pontocerebellar tract arises from pontine nuclei, crosses the midline and reaches the spinocerebellum through the middle cerebellar peduncle of opposite side. Pontine nuclei receive afferents from cerebral cortex. Pontocerebellar tract conveys the information to spinocerebellum about the motor signals discharged from cerebral cortex.

6. *Tectocerebellar tract*

Tectocerebellar tract arises from superior and inferior colliculi of tectum in midbrain. It reaches the spinocerebellum through superior cerebellar peduncle of the same side. This tract carries visual impulses from superior colliculus and auditory impulses from inferior colliculus to spinocerebellum.

7. *Trigeminocerebellar tract*

Trigeminocerebellar tract is formed by the fibers arising from mesencephalic nucleus of trigeminal nerve. It reaches the spinocerebellum via superior cerebellar peduncle of same side. This tract conveys proprioceptive information from jaw muscles and temporomandibular joint to spinocerebellum. It also carries the sensory impulses from the periodontal tissues (tissues around the teeth) to spinocerebellum.

Efferent Connections

Cortex of spinocerebellum is projected into the nuclei fastigi, emboliformis and globosus of cerebellum. Fibers from these nuclei pass through following tracts:

1. *Fastigiobulbar tract*

Fastigiobulbar tract arises from fastigial nucleus, passes through superior cerebellar peduncle of same side and ends in the reticular formation.

2. *Cerebelloreticular tract*

Fibers of cerebelloreticular tract arise from the emboliform and globosus nuclei, pass through superior cerebellar peduncle of same side and terminate in the reticular formation.

From reticular formation, reticulospinal tract arise and terminate on the gamma motor neurons of spinal cord.

3. *Cerebello-olivary tract*

Cerebello-olivary tract arises from the emboliform and globosus nuclei and reaches the inferior olivary nucleus of the same side by passing through the superior cerebellar peduncle. From olivary nucleus, the olivospinal tract arises and fibers of this tract end on the alpha motor neurons of spinal cord.

■ FUNCTIONS

Spinocerebellum regulates **tone, posture** and **equilibrium** by receiving sensory impulses form tactile receptors, proprioceptors, visual receptors and auditory receptors.

Spinocerebellum is the **receiving area** for tactile, proprioceptive, auditory and visual impulses. It also receives the cortical impulses via pontine nuclei. Tactile and proprioceptive impulses are localized in the spinocerebellum. **Localization** of tactile and proprioceptive impulses in spinocerebellum is determined by stimulating the tactile receptors and the proprioceptors and by recording the electrical responses in different parts of spinocerebellum. The different parts of the body are represented in the spinocerebellum in the following manner:

Lingula	:	Coccygeal region
Central lobe	:	Hind limb
Culmen	:	Forelimb
Lobulus simplex	:	Face and head.

In cerebral cortex, different parts of the body are represented in an inverted manner. But in cerebellum, different parts are represented in upright manner.

Spinocerebellum regulates the postural reflexes by modifying muscle tone. It facilitates the discharge from gamma motor neurons in spinal cord via cerebello-vestibulospinal and cerebello-reticulospinal fibers. Increased discharge from gamma motor neurons **increases the muscle tone.** Lesion, destruction or abolishing the function of spinocerebellum by cooling, causes stoppage of discharge from gamma motor neurons, resulting in hypotonia and disturbances in posture.

Spinocerebellum also receives impulses from optic and auditory pathway and helps in adjustment of posture and equilibrium in response to visual and auditory impulses.

■ CORTICOCEREBELLUM (NEOCEREBELLUM)

Corticocerebellum is the largest part of cerebellum. Because of its connection with cerebral cortex, it is

called corticocerebellum or **cerebrocerebellum.** It is phylogenetically newer part of cerebellum. So, it is also called **neocerebellum.** It is concerned with planning, programming and coordination of skilled movements.

■ COMPONENTS

Corticocerebellum includes the lateral portions of cerebellar hemispheres (Fig. 150.1 and Table 150.3).

■ CONNECTIONS

Afferent Connections

1. *Pontocerebellar tract*

Pontocerebellar tract arises from pontine nuclei, crosses the midline and enters corticocerebellum via middle cerebellar peduncle (Fig. 150.7). It is the largest tract in the body having about 20 million nerve fibers.

Pontocerebellar tract is also called the corticopontocerebellar circuit. Because, it receives signals from motor area of cerebral cortex and conveys those signals to corticocerebellum. It helps the cerebellum in planning the movements initiated by the cerebral cortex.

2. *Olivocerebellar tract*

Olivocerebellar tract arises from the inferior olivary nucleus situated in medulla. It crosses the midline and enters corticocerebellum via inferior cerebellar peduncle of the opposite side. There it terminates on the dentate nucleus and cerebellar cortex. This tract is formed by climbing fibers.

Inferior olivary nucleus receives impulses from brainstem, spinal cord and cerebral cortex and conveys these impulses to the corticocerebellum through the olivocerebellar tract.

Efferent Connections

Output signals from corticocerebellum are relayed mainly through the dentate nucleus. Fibers from dentate nucleus pass through superior cerebellar peduncle, cross the midline and form decussation with the fibers of opposite side. After forming the decussation, these fibers divide into two tracts:

1. Dentatothalamic tract
2. Dentatorubral tract.

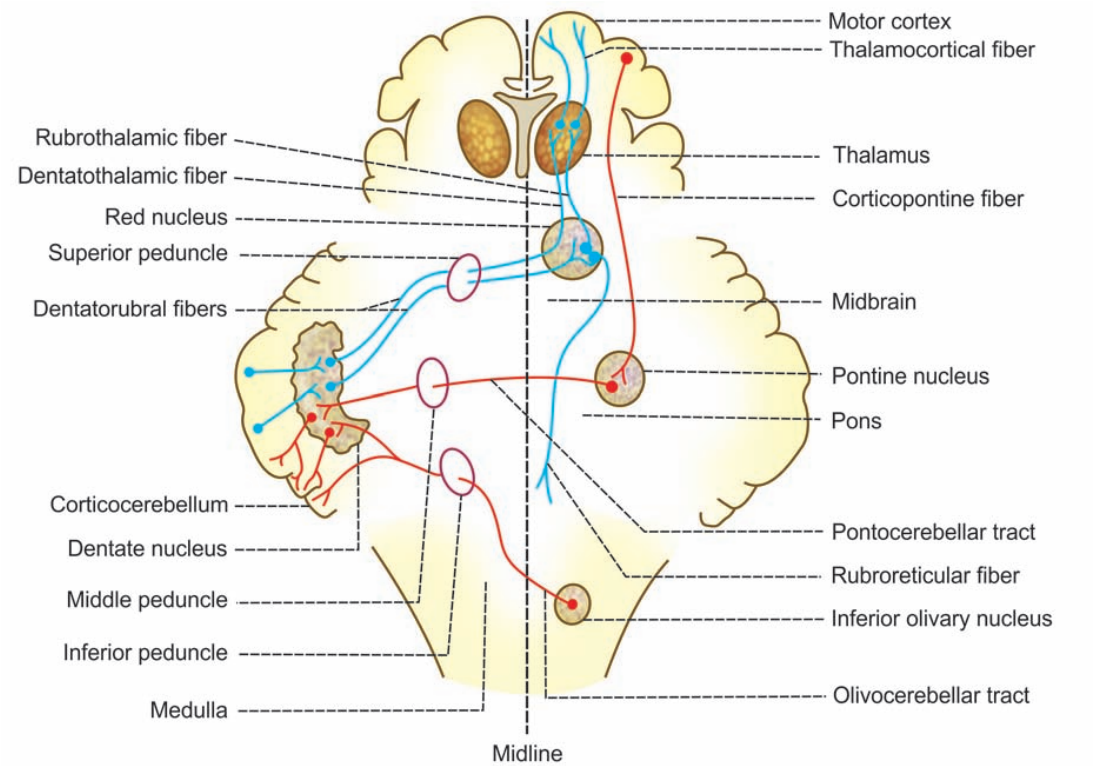

FIGURE 150.7: Connections of corticocerebellum. Red = Afferent connections, Blue = Efferent connections.

1. *Dentatothalamic tract*

After crossing, some of the fibers pass through red nucleus without having any synapse and terminate in lateral ventral nucleus of thalamus. Tract formed by these fibers is called dentatothalamic tract. Thalamus in turn, projects into the motor area of cerebral cortex via thalamocortical fibers.

2. *Dentatorubral tract*

Remaining fibers terminate in the red nucleus of opposite side as dentatorubral tract. Three tracts arise from red nucleus:

i. Rubrothalamic tract: From red nucleus, this tract ascends and terminates in lateral ventral nucleus of thalamus. From here, thalamocortical fibers arise and reach the cerebral cortex.
ii. Rubroreticular tract: It descends down and ends in reticular formation. Reticular formation projects into spinal cord via reticulospinal tract.
iii. Rubrospinal tract: Red nucleus also projects directly into spinal cord through rubrospinal tract.

■ AFFERENT-EFFERENT CIRCUIT (CEREBRO-CEREBELLO-CEREBRAL CONNECTIONS)

Afferent-efferent circuit is an important neuronal pathway, involved in cerebellar control of voluntary movements, initiated by the motor area of cerebral cortex. This pathway includes two tracts:

1. Cerebropontocerebellar tract
2. Dentatorubrothalamocortical tract.

1. *Cerebropontocerebellar Tract*

Fibers from motor areas 4 and 6 in frontal lobe of cerebral cortex enter the pontine nuclei. These fibers are called corticopontine fibers (Figs. 150.8 and 150.9). From pontine nuclei, the pontocerebellar fibers arise and pass through middle cerebellar peduncle of the opposite side and terminate in the cerebellar cortex. This pathway is called the cerebropontocerebellar tract.

2. *Dentatorubrothalamocortical Tract*

Cerebellar cortex is, in turn, connected to the dentate nucleus. Fibers from the dentate nucleus pass via superior cerebellar peduncle and end in red nucleus of opposite side. These fibers are called dentatorubral fibers. From red nucleus, the rubrothalamic fibers go to thalamus. Thalamus is connected to areas 4 and 6 in motor cortex of cerebrum by thalamocortical fibers. This pathway is called dentatorubrothalamocortical tract.

■ FUNCTIONS

Corticocerebellum is concerned with the **integration** and **regulation** of well-coordinated **muscular activities.** It is because of its afferent-efferent connection with cerebral cortex through the cerebro-cerebello-cerebral circuit (Table 150.4). Apart from its connections with cerebral cortex, cerebellum also receives feedback signals from the muscles through the nerve fibers of proprioceptors.

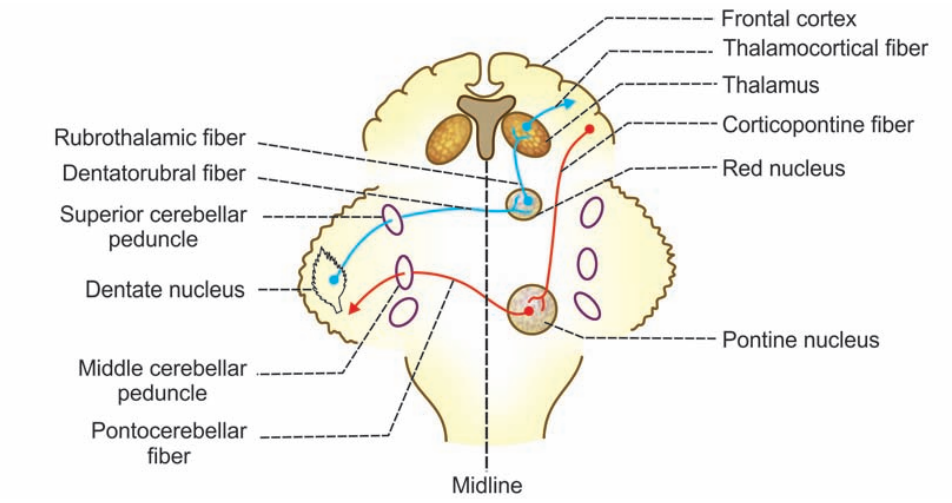

FIGURE 150.8: Cerebro-cerebello-cerebral circuit

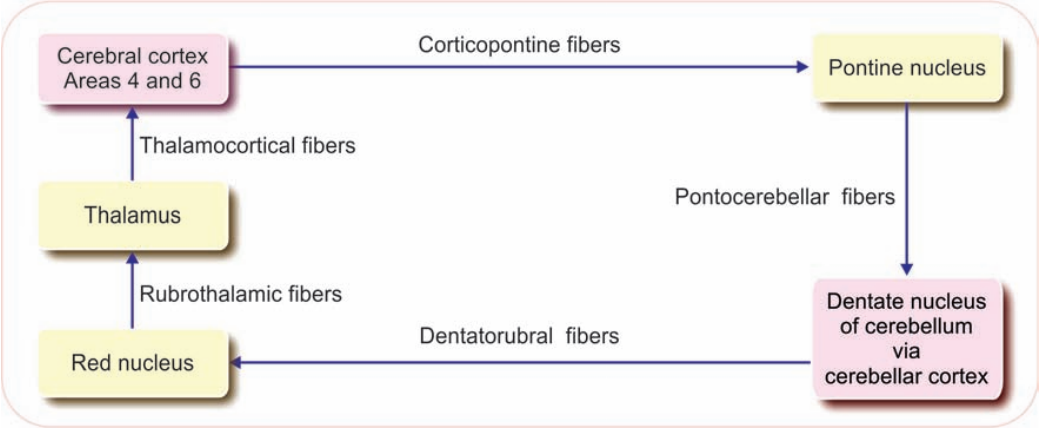

FIGURE 150.9: Schematic representation of cerebro-cerebello-cerebral circuit

TABLE 150.4: Functions of cerebellum

Functions		Division of cerebellum involved
1. Regulation of tone, posture and equilibrium	By receiving impulses from vestibular apparatus	Vestibulocerebellum
	By receiving impulses from proprioceptors in muscles, tendons and joints, tactile receptors, visual receptors and auditory receptors	Spinocerebellum
2. Regulation of coordinated movements	i. Damping action ii. Control of ballistic movements iii. Timing and programming the movements iv. Servomechanism v. Comparator function	Corticocerebellum (Neocerebellum)

Mechanism of Action of Corticocerebellum

1. *Damping action*

Damping action refers to prevention of exaggerated muscular activity. This helps in making the voluntary movements smooth and accurate. All the voluntary muscular activities are initiated by motor areas of cerebral cortex. Simultaneously, corticocerebellum receives impulses from motor cortex as well as feedback signals from the muscles, as soon as the muscular activity starts.

Corticocerebellum, in turn, sends information (impulses) to cerebral cortex to discharge only appropriate signals to the muscles and to cut off any extra impulses. Because of this damping action of corticocerebellum, the exaggeration of muscular activity is prevented and the movements become smooth and accurate. Literally, the word damping means any effect that decreases the amplitude of mechanical oscillation.

2. *Control of ballistic movements*

Ballistic movements are the rapid alternate movements, which take place in different parts of the body while doing any skilled or trained work like typing, cycling, dancing, etc. Corticocerebellum plays an important role in preplanning the ballistic movements during learning process.

3. *Timing and programming the movements*

Corticocerebellum plays an important role in timing and programming the movements, particularly during learning process. While using a typewriter or while doing any other fast-skilled work, a chain of movements occur rapidly in a sequential manner. During the learning process of these skilled works, corticocerebellum plans the various sequential movements. It also plans schedule of time duration of each movement and the time interval between movements. All the information from corticocerebellum are communicated to **sensory motor area** of cerebral cortex and stored in the form of memory. So, after the learning process is over, these activities are executed easily and smoothly in a sequential manner.

4. Servomechanism

Servomechanism is the correction of any disturbance or interference while performing skilled work. Once

the skilled works are learnt, the sequential movements are executed without any interruption. Cerebellum lets the cerebral cortex to discharge the signals, which are already programed and stored at sensory motor cortex and does not interfere much. However, if there is any disturbance or interference, the corticocerebellum immediately influences the cortex and corrects the movements.

5. *Comparator function*

Comparator function of the corticocerebellum is responsible for the integration and coordination of the various muscular activities.

On one side, cerebellum receives the information from cerebral cortex, regarding the cortical impulses which are sent to the muscles. On the other side, it receives the feedback information (proprioceptive impulses) from muscles, regarding their actions under the instruction of cerebral cortex.

By receiving the messages from both ends, corticocerebellum compares the cortical commands for muscular activity and the actual movements carried out by the muscles. If any correction is to be done, then, corticocerebellum sends instructions (impulses) to the motor cortex.

Accordingly, cerebral cortex corrects or modifies the signals to muscles, so that the movements become accurate, precise and smooth. This function of corticocerebellum is known as comparator function.

Simultaneously, it also receives impulses from tactile receptors, eye and ear. Such additional information facilitates the comparator function of corticocerebellum.

■ APPLIED PHYSIOLOGY – CEREBELLAR LESIONS

Cerebellar lesions may be due to tumor, abscess or an injury. Excess alcohol ingestion also leads to cerebellar lesions. Loss of functions of cerebellum also occurs due to degenerative changes in cerebellar cortex, cerebellar nuclei, cerebellar peduncles and spinocerebellar tracts.

In general, during cerebellar lesions, there are disturbances in posture, equilibrium and movements. In unilateral lesion, symptoms appear on the affected side because cerebellum controls the same **(ipsilateral)** side of the body.

Most of the disturbances are due to the damage to corticocerebellum (neocerebellum) because in human beings, it is larger than other divisions.

■ DISTURBANCES IN TONE AND POSTURE

1. *Atonia or Hypotonia*

Atonia is the loss of tone and hypotonia is reduction in tone of the muscle. Cerebellar lesion causes atonia or hypotonia, depending upon the severity of the lesion. Atonia or hypotonia due to cerebellar lesion causes disturbances in the postural reflexes.

Cause for atonia or hypotonia during cerebellar lesion is the loss of facilitatory impulses to gamma motor neurons in the spinal cord via cerebello-vestibulospinal and cerebello-reticulospinal fibers.

2. *Attitude*

Attitude of the body changes in unilateral lesion of the cerebellum. Changes in the attitude are:

i. Rotation of head towards the opposite side (unaffected side)
ii. Lowering of shoulder on the same side
iii. Abduction of leg on the affected side. Leg is rotated outward.
iv. Weight of the body is thrown on leg of unaffected side. So, trunk is bent with concavity towards the affected side.

3. *Deviation Movement*

Deviation movement is the lateral deviation of arms when both the arms are stretched and held in front of the body, with closed eyes. In bilateral lesion, both the arms deviate and in unilateral lesion, arm of the affected side deviates.

4. *Effect on Deep Reflexes*

Pendular movements (Chapter 142) occur while eliciting a tendon jerk. These movements are very common while eliciting the knee jerk or patellar tendon reflex in the patients affected by cerebellar lesion.

A tap on the patellar tendon when leg is hanging freely causes a brisk extension of leg due to the contraction of quadriceps muscle. In normal conditions, after extension, the leg returns back to resting position immediately. In cerebellar lesion, the leg shows pendular movements.

■ DISTURBANCES IN EQUILIBRIUM

While Standing

While standing, the legs are spread to provide a broad base and the body sways side-to-side with oscillations of the head.

While Moving – Gait

Gait means manner of walking. In cerebellar lesion, a staggering, reeling and **drunken-like gait** is observed.

■ DISTURBANCES IN MOVEMENTS

1. *Ataxia:* Lack of coordination of movements.
2. *Asynergia:* Lack of coordination between different groups of muscles such as protagonists, antagonists and synergists.
3. *Asthenia:* Weakness, easy fatigability and slowness of muscles.
4. *Dysmetria:* Inability to check exact strength and duration of muscular contractions required for any voluntary act. While reaching for an object, the arm may overshoot (past pointing) or it may fall short of the object. Overshooting is called **hypermetria** and falling short is known as **hypometria.**
5. *Intention tremor:* Tremor that occurs while attempting to do any voluntary act. Refer Chapter 147 for details of tremor.
6. *Astasia:* Unsteady voluntary movements.
7. *Nystagmus:* To and fro movement of eyeball is called nystagmus. Details of nystagmus are given in Chapter 158.
8. *Rebound phenomenon:* When the patient attempts to do a movement against resistance and if the resistance is suddenly removed, the limb moves forcibly in the direction in which the attempt was made. It is called rebound phenomenon. It is due to the absence of breaking action of antagonistic muscle.
9. *Dysarthria:* Disturbance in speech. It is due to the incoordination of various muscles and structures involved in speech.
10. *Adiadochokinesis:* Ability to do rapid alternate successive movements such as supination and pronation of arm is called **diadochokinesis.** Inability to do rapid alternate successive movements is called adiadochokinesis. It is a common feature of cerebellar lesion. It is also called **dysdiadochokinesia.**

Basal Ganglia

Chapter 151

- INTRODUCTION
- COMPONENTS
  - CORPUS STRIATUM
  - SUBSTANTIA NIGRA
  - SUBTHALAMIC NUCLEUS OF LUYS
- CONNECTIONS
- FUNCTIONS
  - CONTROL OF MUSCLE TONE
  - CONTROL OF MOTOR ACTIVITY
  - CONTROL OF REFLEX MUSCULAR ACTIVITY
  - CONTROL OF AUTOMATIC ASSOCIATED MOVEMENTS
  - ROLE IN AROUSAL MECHANISM
  - ROLE OF NEUROTRANSMITTERS IN THE FUNCTIONS OF BASAL GANGLIA
- APPLIED PHYSIOLOGY – DISORDERS
  - PARKINSON DISEASE
  - WILSON DISEASE
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  - ATHETOSIS
  - CHOREOATHETOSIS
  - HUNTINGTON CHOREA
  - HEMIBALLISMUS
  - KERNICTERUS

INTRODUCTION

Basal ganglia are the scattered **masses of gray matter** submerged in subcortical substance of cerebral hemisphere (Fig. 151.1). Basal ganglia form the part of **extrapyramidal system,** which is concerned with motor activities.

COMPONENTS OF BASAL GANGLIA

Basal ganglia include three primary components:

1. Corpus striatum
2. Substantia nigra
3. Subthalamic nucleus of Luys.

CORPUS STRIATUM

Corpus striatum is a mass of gray matter situated at the base of cerebral hemispheres in close relation to thalamus (Fig. 151.2). Corpus striatum is incompletely divided into two parts by internal capsule:

i. Caudate nucleus
ii. Lenticular nucleus.

i. *Caudate Nucleus*

Caudate nucleus is an elongated arched gray mass, lying medial to internal capsule. Throughout its length, the caudate nucleus is related to lateral ventricle. Caudate nucleus has a head portion and a tail portion.

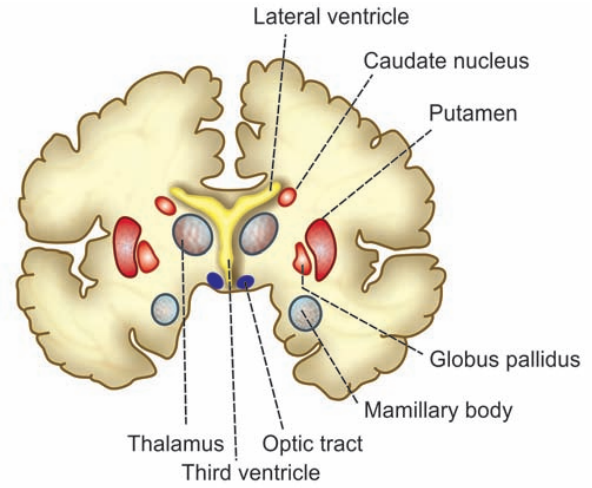

FIGURE 151.1: Basal ganglia

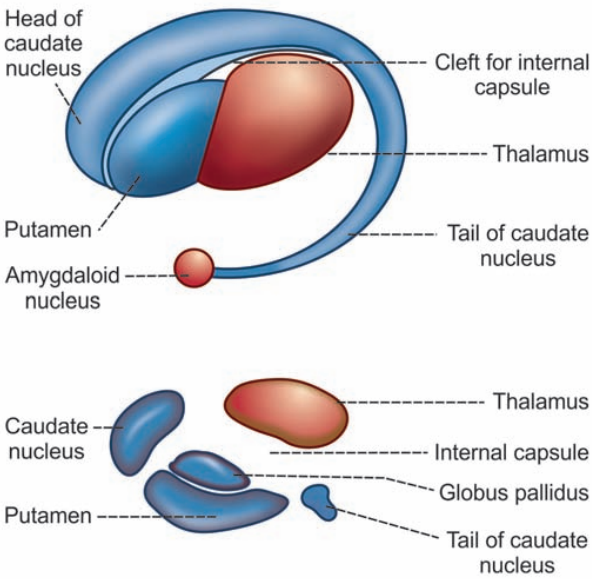

FIGURE 151.2: Corpus striatum

Head is bulged into lateral ventricle and situated rostral to thalamus. The tail is long and arched. It extends along the dorsolateral surface of thalamus and ends in amygdaloid nucleus.

ii. *Lenticular Nucleus*

Lenticular nucleus is a wedge-shaped gray mass, situated lateral to internal capsule. A vertical plate of white matter called **external medullary lamina,** divides lenticular nucleus into two portions:

a. Outer putamen
b. Inner globus pallidus.

Putamen and caudate nucleus are the phylogenetically newer parts of corpus striatum and these two parts are together called **neostriatum** or **striatum.** Globus pallidus is phylogenetically older part of corpus striatum. And, it is called **pallidum** or **paleostriatum.** Globus pallidus has two parts, an outer part and an inner part.

■ SUBSTANTIA NIGRA

Substantia nigra is situated below red nucleus. It is made up of large pigmented and small non-pigmented cells. The pigment contains high quantity of iron.

■ SUBTHALAMIC NUCLEUS OF LUYS

Subthalamic nucleus is situated lateral to red nucleus and dorsal to substantia nigra.

■ CONNECTIONS OF BASAL GANGLIA

Afferent and efferent connections of corpus striatum (Figs. 151.3 and 151.4), substantia nigra and subthalamic nucleus of Luys are given in Table 151.1.

In addition to afferent and efferent connections, different components of corpus striatum of the same side are interconnected by intrinsic fibers.

1. Putamen to globus pallidus
2. Caudate nucleus to globus pallidus
3. Caudate nucleus to putamen.

Different components of corpus striatum in each side are connected to those of the opposite side by commissural fibers.

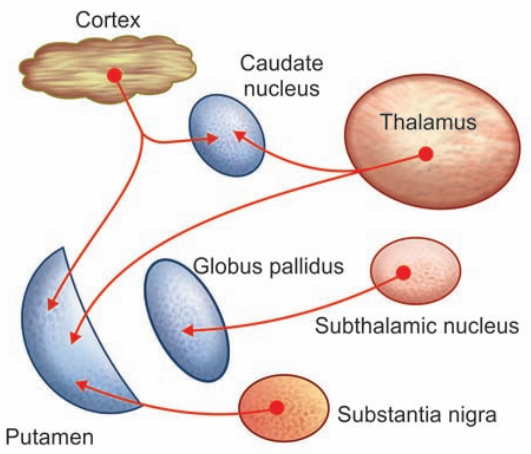

FIGURE 151.3: Afferent connections of corpus striatum

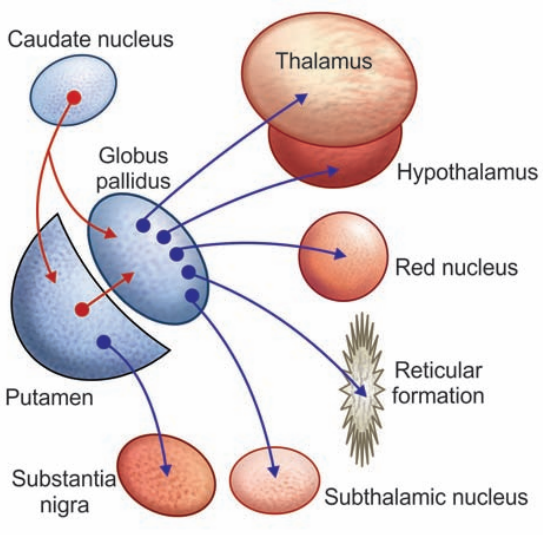

FIGURE 151.4: Efferent and intrinsic connections of corpus striatum

FUNCTIONS OF BASAL GANGLIA

Basal ganglia form the part of **extrapyramidal system,** which is concerned with integration and regulation motor activities. Various functions of basal ganglia are:

1. CONTROL OF MUSCLE TONE

Basal ganglia control the muscle tone. In fact, gamma motor neurons of spinal cord are responsible for development of tone in the muscles (Chapter 157). Basal ganglia **decrease** the **muscle tone** by inhibiting gamma motor neurons through descending inhibitory reticular system in brainstem. During the lesion of basal ganglia, muscle tone increases leading to rigidity.

2. CONTROL OF MOTOR ACTIVITY

i. *Regulation of Voluntary Movements*

Movements during voluntary motor activity are initiated by cerebral cortex. However, these movements are controlled by basal ganglia, which are in close association with cerebral cortex. During lesions of basal ganglia, the control mechanism is lost and so the movements become inaccurate and awkward.

Basal ganglia control the motor activities because of the nervous (neuronal) circuits between basal ganglia and other parts of the brain involved in motor activity. Neuronal circuits arise from three areas of the cerebral cortex:

a. Premotor area
b. Primary motor area
c. Supplementary motor area (Chapter 152).

All these nerve fibers from cerebral cortex reach the caudate nucleus. From here, the fibers go to putamen. Some of the fibers from cerebral cortex go directly to putamen also. Putamen sends fibers to globus pallidus. Fibers from here run towards the thalamus, subthalamic nucleus of Luys and substantia nigra. Subthalamic nucleus and substantia nigra are in turn, projected into thalamus. Now, the fibers from thalamus are projected back into primary motor area and other two motor areas, i.e. premotor area and supplementary motor area.

TABLE 151.1: Connections of basal ganglia

Component	Afferent connections from	Efferent connections to
Corpus striatum	1. Thalamic nuclei to caudate nucleus and putamen 2. Cerebral cortex to caudate nucleus and putamen 3. Substantia nigra to putamen 4. Subthalamic nucleus to globus pallidus	1. Thalamic nuclei 2. Subthalamic nucleus 3. Red nucleus 4. Substantia nigra 5. Hypothalamus 6. Reticular formation (Most of the fibers leave from globus pallidus)
Substantia nigra	1. Putamen 2. Frontal lobe of cerebral cortex 3. Superior colliculus 4. Mamillary body of hypothalamus 5. Medial and lateral lemnisci 6. Red nucleus	Putamen
Subthalamic nucleus of Luys	Globus pallidus	1. Globus pallidus 2. Red nucleus

ii. *Regulation of Conscious Movements*

Fibers between cerebral cortex and caudate nucleus are concerned with regulation of conscious movements. This function of basal ganglia is also known as the **cognitive control** of activity. For example, when a stray dog barks at a man, immediately the person, understands the situation, turns away and starts running.

iii. *Regulation of Subconscious Movements*

Cortical fibers reaching putamen are directly concerned with regulation of some subconscious movements, which take place during trained motor activities, i.e. skilled activities such as writing the learnt alphabet, paper cutting, nail hammering, etc.

■ 3. CONTROL OF REFLEX MUSCULAR ACTIVITY

Some reflex muscular activities, particularly **visual** and **labyrinthine reflexes** are important in maintaining the posture. Basal ganglia are responsible for the coordination and integration of impulses for these reflex activities.

During lesion of basal ganglia, the postural movements, especially the visual and labyrinthine reflexes become abnormal. These abnormal movements are associated with rigidity. Rigidity is because of the loss of inhibitory influence from the cerebral cortex on spinal cord via basal ganglia.

■ 4. CONTROL OF AUTOMATIC ASSOCIATED MOVEMENTS

Automatic associated movements are the movements in the body, which take place along with some motor activities. Examples are the swing of the arms while walking, appropriate facial expressions while talking or doing any work. Basal ganglia are responsible for the automatic associated movements.

Lesion in basal ganglia causes absence of these automatic associated movements, resulting in **poverty of movements.** Face without appropriate expressions while doing any work is called **mask-like face.** Body without associated movements is called **statue-like body.**

■ 5. ROLE IN AROUSAL MECHANISM

Globus pallidus and red nucleus are involved in arousal mechanism because of their connections with reticular formation. Extensive lesion in globus pallidus causes drowsiness, leading to sleep.

■ 6. ROLE OF NEUROTRANSMITTERS IN THE FUNCTIONS OF BASAL GANGLIA

Functions of basal ganglia on motor activities are executed by some neurotransmitters released by nerve endings within basal ganglia. Following neurotransmitters are released in basal ganglia (Table 151.2):

1. Dopamine released by dopaminergic fibers from substantia nigra to corpus striatum (putamen and caudate nucleus: dopaminergic nigrostriatal fibers): deficiency of dopamine leads to parkinsonism
2. Gamma-aminobutyric acid (GABA) secreted by intrinsic fibers of corpus striatum and substantia nigra
3. Acetylcholine released by fibers from cerebral cortex to caudate nucleus and putamen
4. Substance P released by fibers from globus pallidus reaching substantia nigra
5. Enkephalins released by fibers from globus pallidus reaching substantia nigra
6. Noradrenaline secreted by fibers between basal ganglia and reticular formation
7. Glutamic acid secreted by fibers from subthalamic nucleus to globus pallidus and substantia nigra.

Among these neurotransmitters, dopamine and GABA are inhibitory neurotransmitters. So, the fibers

TABLE 151.2: Neurotransmitters involved in the functions of basal ganglia

Neurotransmitter	Released by	Action
1. Dopamine	Fibers from substantia nigra to corpus striatum	Inhibition
2. Gamma aminobutyric acid	Intrinsic fibers of corpus striatum and substantia nigra	Inhibition
3. Acetylcholine	Fibers from cerebral cortex to caudate nucleus and putamen	Excitation
4. Substance P	Fibers from globus pallidus reaching substantia nigra	Excitation
5. Enkephalins	Fibers from globus pallidus reaching substantia nigra	Excitation
6. Noradrenaline	Fibers between basal ganglia and reticular formation	Excitation
7. Glutamic acid	Fibers from subthalamic nucleus to globus pallidus and substantia nigra	Excitation

releasing dopamine and GABA are inhibitory fibers. All other neurotransmitters have excitatory function.

APPLIED PHYSIOLOGY – DISORDERS OF BASAL GANGLIA

1. PARKINSON DISEASE

Parkinson disease is a slowly progressive degenerative disease of nervous system associated with destruction of brain cells, which produce dopamine. It is named after the discoverer **James Parkinson.** It is also called **parkinsonism** or **paralysis agitans.** Great boxer Mohammed Ali is affected by parkinsonism because of repeated blows he might have received on head resulting in damage of brain cells producing dopamine.

Causes of Parkinson Disease

Parkinson disease occurs due to lack of **dopamine** caused by damage of basal ganglia. It is mostly due to the destruction of **substantia nigra** and the **nigrostriatal pathway,** which has dopaminergic fibers. Damage of basal ganglia usually occurs because of the following causes:

i. Viral infection of brain like encephalitis
ii. Cerebral arteriosclerosis
iii. Injury to basal ganglia
iv. Destruction or removal of dopamine in basal ganglia. It occurs mostly due to long-term treatment with antihypertensive drugs like reserpine. Parkinsonism due to the drugs is known as **drug-induced parkinsonism.**
v. Unknown causes: Parkinsonism can occur because of the destruction of basal ganglia due to some unknown causes. This type of parkinsonism is called **idiopathic parkinsonism.**

Signs and Symptoms of Parkinson Disease

Parkinson disease develops very slowly and the early signs and symptoms may be unnoticed for months or even for years. Often the symptoms start with a mild noticeable tremor in just one hand. When the tremor becomes remarkable the disease causes slowing or freezing of movements followed by rigidity.

Following are the common signs and symptoms of Parkinson disease:

i. *Tremor*

Refer Chapter 147 for details of tremor. In Parkinson disease, the tremor occurs during rest. But it disappears while doing any work. So, it is called **static tremor** or **resting tremor.** It is also called **drum-beating tremor,** as the movements are similar to beating a drum. Thumb moves rhythmically over the index and middle fingers. These movements are called **pill-rolling movements.**

ii. *Slowness of movements*

Over the time, movements start slowing down **(brady-kinesia)** and it takes a long time even to perform a simple task. Gradually the patient becomes unable to initiate the voluntary activity **(akinesia)** or the voluntary movements are reduced **(hypokinesia).** It is because of hypertonicity of the muscles.

iii. *Poverty of movements*

Poverty of movements is the loss of all automatic associated movements. Because of absence of the automatic associate movements, the body becomes **statue-like.** The face becomes **mask-like,** due to absence of appropriate expressions like blinking and smiling.

iv. *Rigidity*

Stiffness of muscles occurs in limbs resulting in rigidity of limbs. The muscular stiffness occurs because of increased muscle tone which is due to the removal of inhibitory influence on gamma motor neurons. It affects both flexor and extensor muscles equally. So, the limbs become more **rigid like pillars.** The condition is called **lead-pipe rigidity.** In later stages the rigidity extends to neck and trunk.

v. *Gait*

Gait refers to manner of walking. The patient looses the normal gait. Gait in Parkinson disease is called **festinant gait.** The patient walks quickly in short steps by bending forward as if he is going to catch up the center of gravity.

vi. *Speech problems*

Many patients develop speech problems. They may speak very softly or sometimes rapidly. The words are repeated many times. Finally, the speech becomes slurred and they hesitate to speak.

vii. *Emotional changes*

The persons affected by Parkinson disease are often upset emotionally.

viii. *Dementia*

In later stages, some patients develop dementia (Chapter 162).

Treatment for Parkinson Disease

As Parkinson disease is due to lack of dopamine caused by damage of dopaminergic fibers, it is treated by **dopamine injection.**

Dopamine does not cross the blood-brain barrier. So, another substance called **levodopa** (L-dopa) which crosses the blood-brain barrier is injected. L-dopa moves into the brain and there it is converted into dopamine. Since, L-dopa can be converted into dopamine in liver, some side effects occur due to excess dopamine content in liver and blood. So, along with L-dopa, another substance called **carbidopa** is administered. Carbidopa prevents the conversion of L-dopa into dopamine and carbidopa cannot pass through blood-brain barrier. Thus, L-dopa moves into the brain tissues and is converted into dopamine.

Some of the symptoms of Parkinson disease such as tremor are abolished by **surgical destruction** of basal ganglia or thalamic nuclei.

■ 2. WILSON DISEASE

Wilson disease is an inherited disorder characterized by excess of copper in the body tissues. It is also known as **progressive hepatolenticular degeneration.** This disease develops due to damage of the lenticular nucleus particularly, putamen.

In Wilson disease, copper is deposited in the liver, brain, kidneys and eyes. **Copper deposits** cause damage of tissues. And the affected organs stop functioning.

In addition to symptoms of Parkinson disease, **liver failure** and damage to the central nervous system are the most predominant effects of this disorder. Wilson disease is fatal if not treated early.

■ 3. CHOREA

Chorea is an abnormal involuntary movement. Chorea means **rapid jerky movements.** It mostly involves the limbs. Chorea is due to the lesion in caudate nucleus and putamen.

■ 4. ATHETOSIS

Athetosis is another type of abnormal involuntary movement, which refers to slow **rhythmic and twisting movements.** It is because of the lesion in caudate nucleus and putamen.

■ 5. CHOREOATHETOSIS

Choreoathetosis is the condition characterized by aimless involuntary muscular movements. It is due to combined effects of chorea and athetosis.

■ 6. HUNTINGTON CHOREA

Huntington disease is an inherited progressive neural disorder due to the degeneration of neurons secreting GABA in corpus striatum and substantia nigra. This disease starts mostly in middle age. It is characterized by chorea, hypotonia and dementia. In severe cases bilateral wasting of muscles occurs. It is otherwise called **Huntington disease, chronic progressive chorea, degenerative chorea** or **hereditary chorea.**

■ 7. HEMIBALLISMUS

Hemiballismus is a disorder characterized by violent involuntary abnormal movements on one side of the body involving mostly the arm. While walking, the arm swings widely. These movements are called the **flinging movements.** These movements are due to the **release phenomenon** because of the absence of inhibitory influence on movements. Hemiballismus occurs due to degeneration of subthalamic nucleus of Luys.

■ 8. KERNICTERUS

Kernicterus is a form of brain damage in infants caused by **severe jaundice.** Basal ganglia are the mainly affected parts of brain. Refer Chapter 21 for details.

Cerebral Cortex

Chapter 152

- INTRODUCTION
- HISTOLOGY OF CEREBRAL CORTEX
  - LAYERS OF CEREBRAL CORTEX
  - PARTS OF CEREBRAL CORTEX
- LOBES OF CEREBRAL CORTEX
- CEREBRAL DOMINANCE
  - CEREBRAL DOMINANCE AND HANDEDNESS
- BRODMANN AREAS
- FRONTAL LOBE
  - PRECENTRAL CORTEX
  - PREFRONTAL CORTEX OR ORBITOFRONTAL CORTEX
  - APPLIED PHYSIOLOGY – FRONTAL LOBE SYNDROME
- PARIETAL LOBE
  - SOMESTHETIC AREA I
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  - SOMESTHETIC ASSOCIATION AREA
  - APPLIED PHYSIOLOGY
- TEMPORAL LOBE
  - PRIMARY AUDITORY AREA
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- OCCIPITAL LOBE
  - AREAS OF VISUAL CORTEX
  - APPLIED PHYSIOLOGY
- METHODS TO STUDY CORTICAL CONNECTIONS AND FUNCTIONS
  - BY CUTTING OR DESTRUCTION OF NERVE CELL
  - BY RECORDING ELECTRICAL ACTIVITY – EVOKED POTENTIAL
  - BY PHYSIOLOGICAL NEURONOGRAPHY
  - BY SCANNING

INTRODUCTION

Cerebral cortex is also called **pallidum** and it consists of two hemispheres. Surface area of cerebral cortex in human beings is 2.2 sq m.

Both the **cerebral hemispheres** are separated by a deep **vertical fissure** (deep furrow or groove). The separation is complete anteriorly and posteriorly. But in middle portion, the fissure extends only up to corpus callosum. **Corpus callosum** is the broad band of commissural fibers, connecting the two hemispheres.

Surface of the cerebral cortex is characterized by complicated pattern of sulci (singular = sulcus) and

gyri (singular = gyrus). Sulcus is a slight depression or groove and gyrus is a raised ridge.

HISTOLOGY OF CEREBRAL CORTEX

LAYERS OF CEREBRAL CORTEX

Cerebral cortex consists of **gray matter** that surrounds the deeper **white matter.** It is formed by different types of nerve cells along with their processes and neuroglia. It is not uniform throughout. It is thickest, i.e. 4.5 cm at the precentral gyrus and thinnest at frontal and occipital poles. According to **Economo,** the cerebral cortex is formed by six layers of structures. Following are the layers from outside to inside:

1. *Molecular or Plexiform Layer*

Molecular layer has few small fusiform cells. It also contains dendrites or axons from cells of deeper layers.

2. *External Granular Layer*

External granular layer consists of large number of closely packed small cells, which are round, polygonal or triangular in shape. Dendrites of these cells pass into molecular layer. Axons end in the deeper layers. Some axons enter white substance of the hemisphere.

3. *Outer Pyramidal Layer*

Outer pyramidal layer is formed by **pyramidal cells,** which are of two sizes. Medium sized pyramidal cells are in the outer portion and larger pyramidal cells are in deeper portion.

4. *Internal Granular Layer*

Like external granular layer, this layer also has closely packed smaller cells, which are **stellate type.** But, the nerve fibers are more in this layer than in external granular layer. This layer contains many **horizontal fibers,** which appear as a white strip known as **outer strip.**

5. *Ganglionic Layer or Internal Pyramidal Layer*

Ganglionic layer or internal pyramidal layer consists of **pyramidal cells** of graded sizes. It is well developed in the precentral (motor) cortex. Pyramidal cells in this region are otherwise known as **Betz cells** or **giant cells.** This layer also contains **cells of Martinotti.** Martinotti cells are peculiar in that their axons pass outward towards the surface of the cortex.

6. *Fusiform Cell Layer*

Fusiform cell layer is in contact with white matter of cerebral hemisphere. It is composed of closely packed small spindle-shaped cells.

PARTS OF CEREBRAL CORTEX

Cerebral cortex is divided into two parts based on phylogeny (evolutionary development of a species):

1. Neocortex
2. Allocortex.

1. *Neocortex*

Neocortex is the phylogenetically new structure of cerebral cortex. It is also called **isocortex** or **neopallium.**

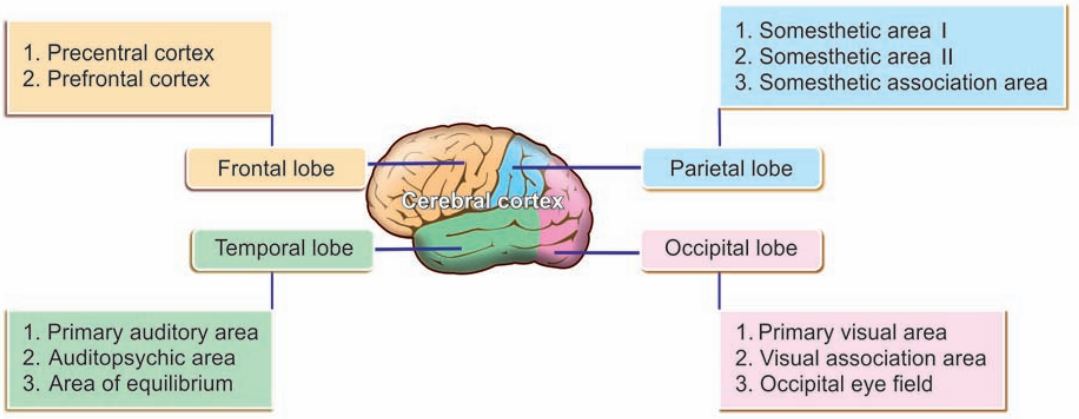

FIGURE 152.1: Parts of cerebral cortex

This part forms the major portion of cerebral cortex.

Part of the cerebral cortex that has all six layers of structures is called neocortex.

2. *Allocortex*

Allocortex is the phylogenetically oldest structure of cerebral cortex. It has less than six layers of structures. It is divided into two divisions namely, **archicortex** and **paleocortex,** which form the parts of **limbic system** (Chapter 153).

■ LOBES OF CEREBRAL CORTEX

In each hemisphere, there are three surfaces lateral, medial and inferior surfaces. **Neocortex** of each cerebral hemisphere consists of four lobes (Figs. 152.1 to 152.3):

1. Frontal lobe
2. Parietal lobe
3. Occipital lobe
4. Temporal lobe.

Lobes of each hemisphere are demarcated by four main fissures and sulci:

1. **Central sulcus** or **Rolandic fissure** between frontal and parietal lobes
2. **Parieto-occipital sulcus** between parietal and occipital lobe
3. **Sylvian fissure** or **lateral sulcus** between parietal and temporal lobes
4. **Callosomarginal fissure** between temporal lobe and limbic area.

■ CEREBRAL DOMINANCE

Cerebral dominance is defined as the dominance of one cerebral hemisphere over the other in the control of cerebral functions. Both the cerebral hemispheres are not functionally equivalent. Some functional asymmetries are well known.

■ CEREBRAL DOMINANCE AND HANDEDNESS

Cerebral dominance is related to handedness, i.e. preference of the individual to use right or left hand. More than 90% of people are **right handed.** In these individuals, the left hemisphere is dominant and it controls the analytical process and language related functions such as speech, reading and writing. Hence, left hemisphere of these persons is called **dominant or categorical hemisphere.**

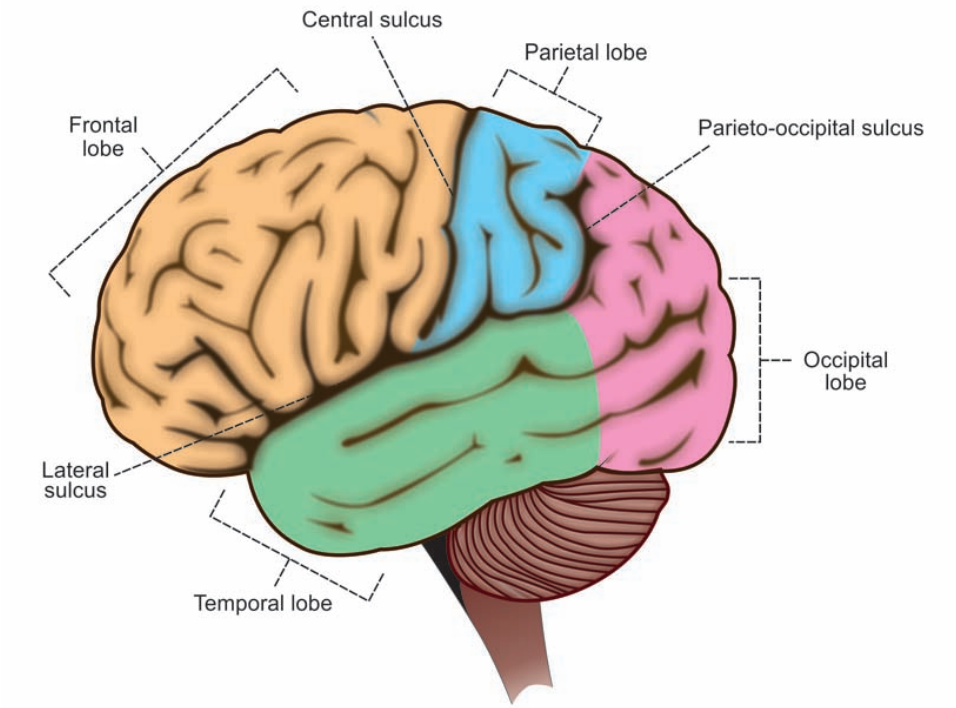

FIGURE 152.2: Lobes of cerebral cortex

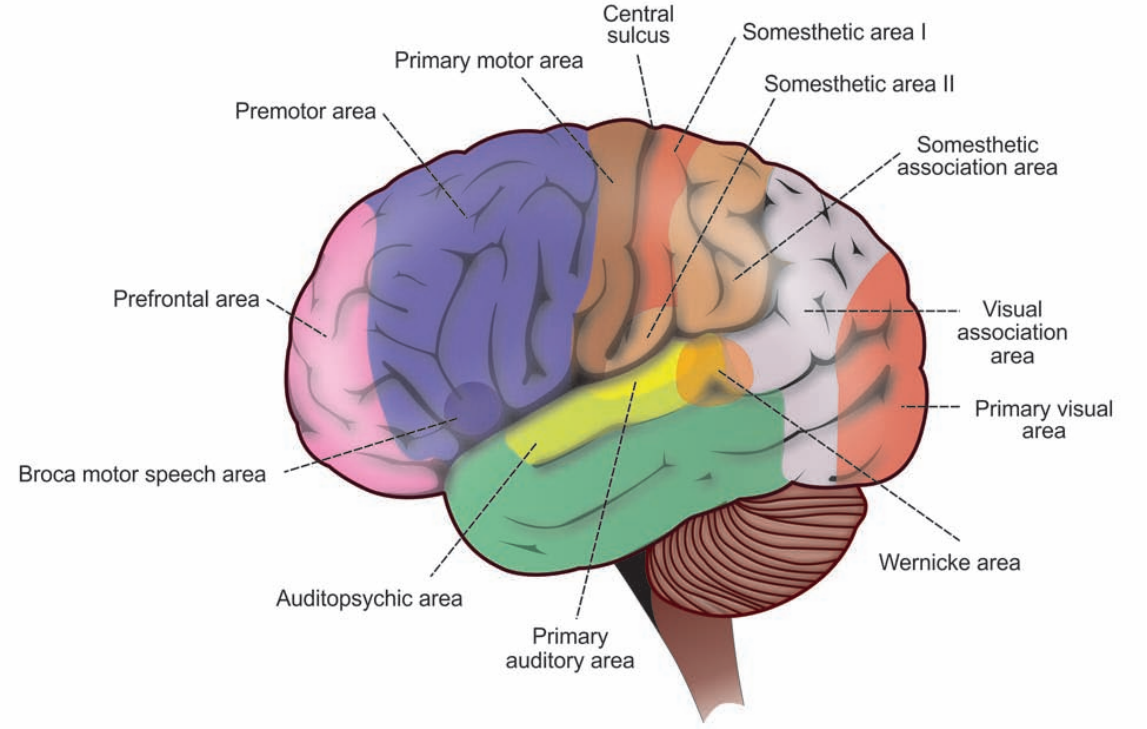

FIGURE 152.3: Functional regions on lateral surface of cerebral cortex

Right hemisphere is called **representational hemisphere** since it is associated with artistic and visuospatial functions like judging the distance, determining the direction, recognizing the tones, etc.

Lesion in dominant hemisphere leads to language disorders. Lesion in representational hemisphere causes only mild effects like astereognosis.

Left hemisphere is the dominant hemisphere in about 75% of the right-handed persons. In the remaining left-handed persons, right hemisphere controls the language function. Some of these persons do not have dominant hemisphere.

BRODMANN AREAS

Brodmann area is a region of cerebral cortex defined on the basis of its **cytoarchitecture.** Cytoarchitecture means organization of cells. Brodmann areas were originally defined and numbered in 1909 by **Korbinian Brodmann** depending upon the laminar organization of neurons in the cortex. Some of these areas were given specific names based on their functions. During the period of a century Brodmann areas had been extensively discussed and renamed.

FRONTAL LOBE OF CEREBRAL CORTEX

Frontal lobe forms one third of the cortical surface. It extends from frontal pole to the central sulcus and limited below by the lateral sulcus. Frontal lobe of cerebral cortex is divided into two parts:

A. Precentral cortex, which is situated posteriorly
B. Prefrontal cortex, which is situated anteriorly.

PRECENTRAL CORTEX

Precentral cortex forms the posterior part of frontal lobe. It includes the lip of central sulcus, whole of precentral gyrus and posterior portions of superior, middle and inferior frontal gyri. It also extends to the medial surface.

This part of cerebral cortex is also called excitomotor cortex or area, since the stimulation of different points in this area causes activity of discrete skeletal muscle. Precentral cortex is further divided into three functional areas (Fig. 152.3):

1. Primary motor area
2. Premotor area
3. Supplementary motor area.

1. *Primary Motor Area*

Primary motor area extends throughout the precentral gyrus and the adjoining lip of central sulcus. Areas 4 and 4S are present here.

Structure of primary motor area

Though this area has all the six layers, the granular layer is thin. Special structural feature of this layer is the presence of **giant pyramidal cells** called **Betz cells** in ganglionic layer.

Connections of primary motor area

Efferent connections

i. Fibers of pyramidal tracts arise from the Betz cells. These fibers synapse with motor neurons in anterior gray horn of opposite side (few fibers reach the same side motor neurons) in spinal cord
ii. Frontopontine fibers from this area reach pontine nuclei of same side
iii. Fibers are also projected to corpus striatum, red nucleus, thalamus, subthalamus and reticular formation
iv. Association fibers connect the primary motor area to other areas of cortex.

Afferent connections

Primary motor area receives fibers from dentate nucleus (cerebellum) via red nucleus and thalamus.

Functions of primary motor area

Primary motor area is concerned with initiation of voluntary movements and speech.

Area 4

It is a tapering strip of area situated in precentral gyrus of frontal lobe. Broad end lies superiorly at the upper border of hemisphere and most of the efferent fibers of primary motor area arise from this area (Figs. 152.4 and 152.5).

Function of area 4

Area 4 is the center for movement, as it sends all efferent (corticospinal) fibers of primary motor area. Through the fibers of corticospinal tracts, area 4 activates the lower motor neurons in the spinal cord. It activates both **α-motor neurons** and **γ-motor neurons** simultaneously by the process called **coactivation** (Chapter 157).

Activation of α-motor neurons causes contraction of **extrafusal fibers** of the muscles. Activation of γ-motor neurons causes contraction of **intrafusal fibers** leading to increase in muscle tone.

Effect of stimulation of area 4

Electrical stimulation of area 4 causes discrete **isolated movements** in the opposite side of the body. The groups of muscles or single isolated muscle may be activated depending upon the area stimulated.

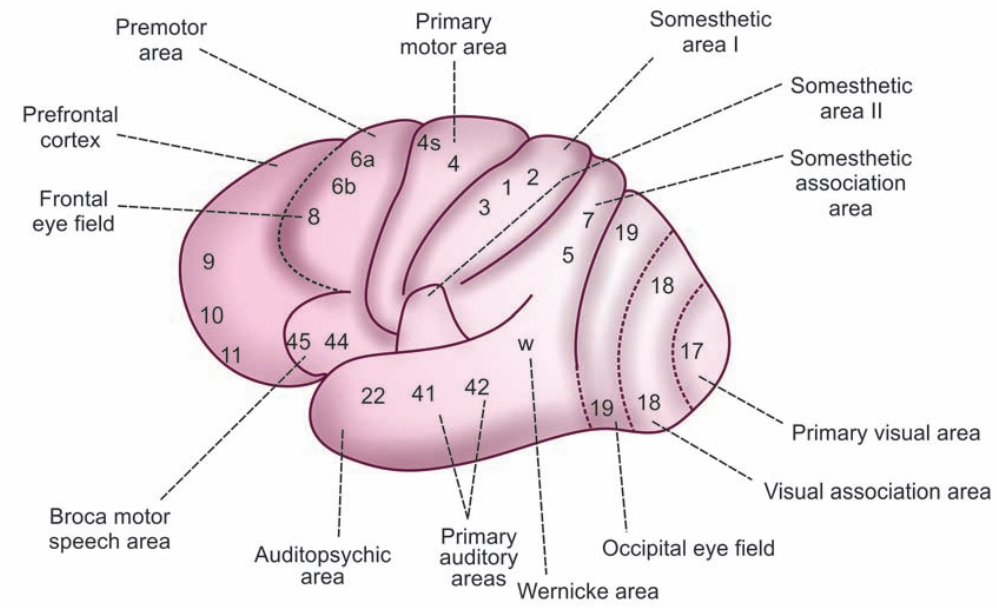

FIGURE 152.4: Lateral surface of cerebral cortex

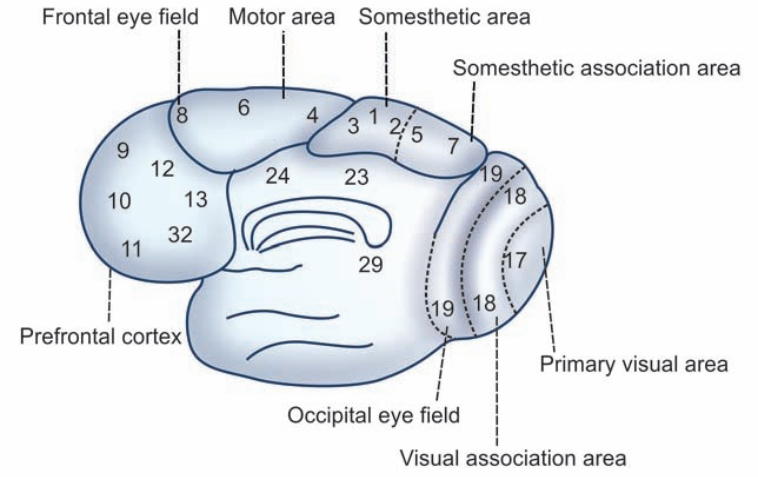

FIGURE 152.5: Medial surface of cerebral cortex

Localization – homunculus

Muscles of various parts of the body are represented in area 4 in an **inverted way** from medial to lateral surface. Lower parts of body are represented in medial surface and upper parts of the body are represented in the lateral surface.

Order of representation from medial to lateral surface: Toes, ankle, knee, hip, trunk, shoulder, arm, elbow, wrist, hand fingers and face. However, parts of the face are not represented in inverted manner (Fig. 152.6).

Area 4 is concerned with contraction of discrete muscles. It sends motor signals to the facial muscles of both sides (bilateral) and the other muscles of the opposite side (contralateral).

Effect of lesion of area 4

Effect of lesion or ablation of area 4 differs in different species. In cats, the ability to walk is not affected. In monkeys, there is contralateral flaccid paralysis, hypotonia and loss of reflexes. Myotatic reflexes reappear in a short time. Recovery occurs only in proximal parts of limbs but the digits remain permanently paralyzed.

In man, the symptoms are severe than in monkeys. In unilateral lesion, paralysis occurs in **contralateral side.** Complete paralysis is rare. If both sides are affected, the effect is more severe. Recovery occurs very slowly. During recovery, upper parts of body recover first.

If area 4 is affected along with area 6, the effect is very severe, causing **hemiplegia** with **spastic paralysis.** Hemiplegia means the paralysis in one half of the body. In spastic paralysis, the muscles undergo spastic contraction due to increased muscle tone.

Area 4S

Area 4S is called **suppressor area.** It forms a narrow strip anterior to area 4. It scrutinizes and suppresses the extra impulses produced by area 4 and inhibits exaggeration of movements.

2. *Premotor Area*

Premotor area includes areas 6, 8, 44 and 45. The premotor area is anterior to primary motor area in the precentral cortex. The premotor area is concerned with control of postural movements by sending motor signals to **axial muscles** (muscles near the midline of the body).

Structure of premotor area

Premotor area is similar to primary motor area in structure except for the absence of giant pyramidal cells in ganglionic layer.

Area 6

Area 6 is in the posterior portions of superior, middle and inferior frontal gyri. It is subdivided into 6a and 6b. It gives origin to some of the pyramidal tract fibers. The other connections are similar to those of area 4.

Functions of area 6

Area 6 has two functions:

i. It is concerned with **coordination of movements** initiated by area 4. It helps to make the skilled movements more accurate and smooth.
ii. It is believed to be the **cortical center** for **extrapyramidal system.**

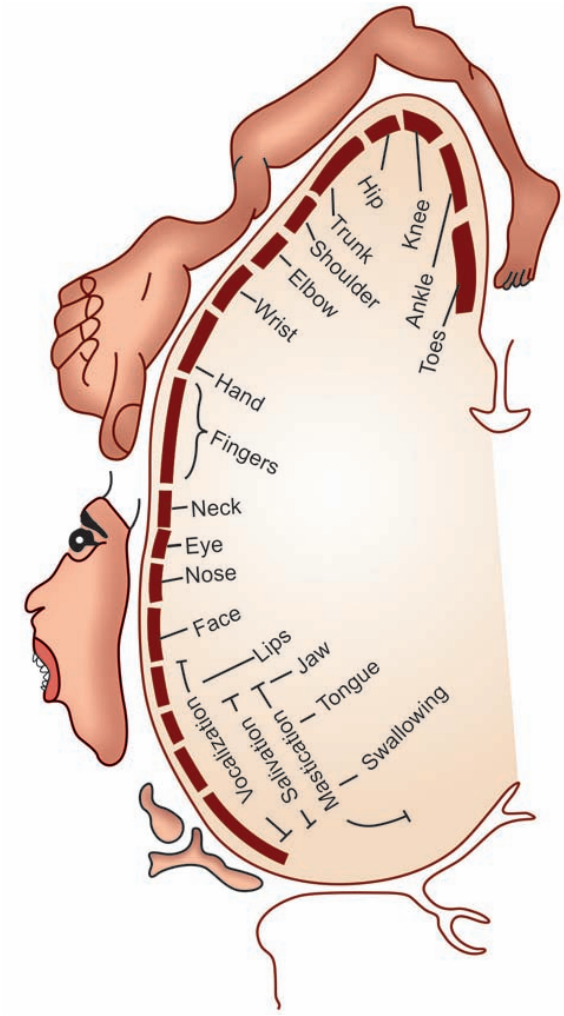

FIGURE 152.6: Topographical arrangement (homunculus) of motor areas in cerebral cortex

Effect of stimulation of area 6

Electrical stimulation of area 6a in human being causes the same effects as the stimulation of area 4. However, the stimulus must be stronger to evoke response from area 6. The effects of stimulation of this area are:

i. Stimulation of area 6a causes **generalized pattern of movements** like rotation of head, eyes and trunk towards the opposite side
ii. Stimulation of 6b produces rhythmic, **complex coordinated movements** involving the muscles of face, buccal cavity, larynx and pharynx.

Effect of lesion of area 6

Lesion or removal of area 6 in monkeys leads to loss of skilled movements. After the lesion, the recovery may occur; but the movements become awkward. It also produces **grasping reflexes.** Lesion involving areas 6 and area 4 produces severe symptoms of **hemiplegia** with **spastic paralysis.**

Area 8

Area 8 is called **frontal eye field.** It lies anterior to area 6 in the precentral cortex. It is concerned with movements of eyeball.

This area receives afferent fibers from dorsomedial nucleus of thalamus and occipital lobe. It sends efferent fibers to oculomotor nuclei in tegmentum of midbrain.

Function of area 8

Frontal eye field is concerned with **conjugate movement** of eyeballs (Chapter 165). This area initiates voluntary scanning movements of eyeballs and it is independent of visual stimuli. It is also responsible for opening and closing of eyelids, pupillary dilatation and lacrimation.

Effect of stimulation of area 8

Stimulation of this area causes conjugate movements of eyeballs to the opposite side.

Effect of lesion of area 8

Lesion of this area turns the eyes to the affected side. Conjugate movements of eyes are lost. However, pupils and eyelids are not affected. In animals, while walking, circular movements occur towards the affected side.

Broca area

Broca area is the **motor area for speech.** It includes areas 44 and 45. Broca area is present in left hemisphere (dominant hemisphere) of right-handed persons and in the right hemisphere of left-handed persons. It is a special region of premotor cortex situated in inferior frontal gyrus. Area 44 is situated in pars triangularis and 45 in pars opercularis of this gyrus.

Function of Broca area

Broca area is responsible for movements of tongue, lips and larynx, which are involved in **speech.**

Effect of lesion of Broca area

Lesion in Broca area leads to **aphasia** (Chapter 162).

3. *Supplementary Motor Area*

Supplementary motor area is situated in medial surface of frontal lobe rostral to primary motor area. Various motor movements are elicited by electrical stimulation of this area like raising the contralateral arm, turning the head and eye and movements of synergistic muscles of trunk and legs.

Function of supplementary motor area

Exact function of this area is not understood clearly. It is suggested that it is concerned with **coordinated skilled movements.**

Effect of lesion of supplementary motor area

During lesion in this area of human being, the head and eyeballs turn towards the affected side.

Destruction of this area in monkeys causes weak grasping reflexes in contralateral side and bilateral hypertonia of shoulder muscles. But, paralysis is not noticed.

■ PREFRONTAL CORTEX OR ORBITOFRONTAL CORTEX

Prefrontal cortex is the anterior part of frontal lobe of cerebral cortex, in front of areas 8 and 44. It occupies the medial, lateral and inferior surfaces and includes orbital gyri, medial frontal gyrus and the anterior portions of superior, middle and inferior frontal gyri.

Areas present in prefrontal cortex are 9, 10, 11, 12, 13, 14, 23, 24, 29 and 32. Areas 12, 13, 14, 23, 24, 29 and 32 are in medial surface (Table 152.1). Areas 9, 10 and 11 are in lateral surface.

Connections of Prefrontal Cortex

Afferent fibers

Afferent fibers of prefrontal cortex come from:

1. Dorsomedial nucleus of thalamus
2. Hypothalamus
3. Corpus striatum
4. Amygdala
5. Midbrain.

Areas 23, 24, 29 and 32 receive fibers from anterior nucleus of thalamus. Area 32 receives fibers from suppressor area of precentral cortex also.

Efferent fibers

Efferent fibers are projected to:

1. Thalamus
2. Hypothalamus
3. Tegmentum
4. Caudate nucleus
5. Pons
6. Temporal lobe of cerebral cortex.

Area 13, along with hippocampus, uncus and amygdala sends fibers to mamillary body of hypothalamus via fornix. This area is concerned with **emotional reactions.**

Functions of Prefrontal Cortex

Earlier, this area was considered as inexcitable to electrical stimulation. Hence, it was called the **silent area** or **association area.** But, now it is known that the stimulation of this area with low voltage electrical stimulus causes changes in the activity of digestive, cardiovascular, respiratory and excretory systems and other autonomic functions. It also causes fear. Various functions of prefrontal cortex are:

1. It forms the center for the higher functions like emotion, learning, memory and social behavior. **Short-term memories** are registered here.
2. It is the center for **planned actions**
3. This area is the **seat of intelligence;** so, it is also called the **organ of mind**
4. It is responsible for the **personality** of the individuals
5. Prefrontal cortex is responsible for the various **autonomic changes** during emotional conditions, because of its connections with hypothalamus and brainstem.

Effect of Lesion of Prefrontal Cortex

Bilateral lesion or removal of prefrontal cortex in human beings does not cause paralysis. It causes lack of initiation and loss of mental alertness. Very little or no change occurs in memory, judgment and intelligence.

■ APPLIED PHYSIOLOGY – FRONTAL LOBE SYNDROME

Injury or ablation of prefrontal cortex leads to a condition called frontal lobe syndrome.

Features of this syndrome are:

1. **Emotional instability:** There is lack of restraint, leading to hostility, aggressiveness and restlessness
2. **Lack of concentration** and lack of fixing attention
3. There is **lack of initiation** and difficulty in planning any course of action
4. Impairment of **recent memory** occurs. However, the memory of remote events is not lost.
5. Loss of **moral and social sense** is common and there is loss of love for family and friends
6. There is failure to realize the seriousness of the condition. The subject has the sense of well-being and also has **flight of ideas.**
7. Apart from mental defects, there are some functional abnormalities also:
   i. **Hyperphagia** (increased food intake)
   ii. Loss of control over sphincter of the urinary bladder or rectum
   iii. Disturbances in orientation
   iv. Slight tremor.

TABLE 152.1: Areas and connections of frontal lobe

Areas		Afferent fibers from	Efferent fibers to
Precentral cortex	Primary motor areas 4, 4s	1. Cerebellum (Dentate nucleus – via red nucleus) 2. Thalamus	1. Corticospinal tract 2. Pons 3. corpus striatum 4. Red nucleus 5. Thalamus 6 Subthalamus 7. Reticular formation
	Premotor areas 6, 8, 44, 45		
	Supplementary area		
Prefrontal cortex	Areas 9, 10, 11, 12, 13, 14, 29, 23, 24, 32	1. Thalamus 2. Hypothalamus 3. Corpus striatum 4. Amygdala 5. Midbrain	1. Thalamus 2. Hypothalamus 3. Tegmentum 4. Caudate nucleus 5. Temporal lobe

■ PARIETAL LOBE

Parietal lobe extends from central sulcus and merges with occipital lobe behind and temporal lobe below. This lobe is separated from occipital lobe by parieto-occipital sulcus and from temporal lobe by Sylvian sulcus. Parietal lobe is divided into three functional areas:

A. Somesthetic area I
B. Somesthetic area II
C. Somesthetic association area.

In addition to these three areas, a part of sensory motor area is also situated in parietal lobe (see below).

■ SOMESTHETIC AREA I

Somesthetic area I is also called **somatosensory area** I or primary somesthetic or primary sensory area. It is present in the posterior lip of central sulcus, in the postcentral gyrus and in the paracentral lobule.

Areas of Somesthetic Area I

Somesthetic area I has three areas, which are called areas 3, 1 and 2. Anterior part of this forms area 3 and posterior part forms areas 1 and 2.

Connections of Somesthetic Area I

Somesthetic area I receives sensory fibers from thalamus via parietal part of thalamic radiation.

Localization – Homunculus

Different sensory areas of the body are represented in postcentral gyrus (primary sensory area) in an **inverted manner** as in the motor area. Toes are represented in lowest part of medial surface, legs at the upper border of hemispheres, then from above downwards knee, thigh, hip, trunk, upper limb, neck and face. Representation of face is not inverted. Representation of parts of face from above downwards is eyelids, nose, cheek, upper lip and lower lip (Fig. 152.7).

Functions of Somesthetic Area I

1. Somesthetic area I is responsible for perception and integration of **cutaneous** and **kinesthetic sensations.** It receives sensory impulses from cutaneous receptors (touch, pressure, pain, temperature) and proprioceptors of opposite side through thalamic radiation. Area 1 is concerned with sensory perception. Areas 3 and 2 are involved in the integration of these sensations.
2. This area sends **sensory feedback** to the premotor area
3. This area is also concerned with the movements of head and eyeballs
4. Discriminative functions: In addition to perception of cutaneous and kinesthetic sensation, this area is also responsible for recognizing the **discriminative features** of sensations.
   Discriminative functions are:
   i. Spatial recognition: Tactile localization, two point discrimination and recognition of position and passive movements of limbs
   ii. Recognition of intensity of different stimuli
   iii. Recognition of similarities and differences between the stimuli.

Effect of Stimulation of Somesthetic Area I

Electrical stimulation of somesthetic area I produces vague sensations like numbness and tingling.

Effects of Lesion of Somesthetic Area I

If lesion occurs only in the sensory area without involvement of thalamus, the sensations are still perceived.

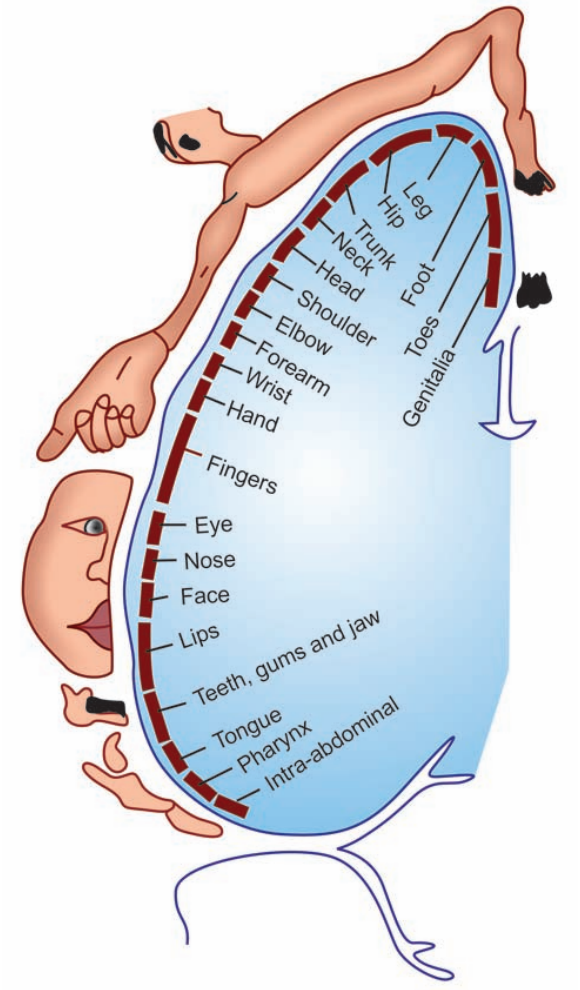

FIGURE 152.7: Topographical arrangement (homunculus) of sensory areas in cerebral cortex

But, the discriminative functions are lost. If thalamus also is affected by lesion, there is loss of sensations in the opposite side of the body.

■ SOMESTHETIC AREA II

Somesthetic area II is situated in postcentral gyrus below the area of face of somesthetic area I. A part of this is buried in Sylvian sulcus. It is also known as secondary somesthetic area or somatosensory area II.

Functions of Somesthetic Area II

Somesthetic area II receives sensory impulses from somesthetic area I and from thalamus directly. Though the exact role of this area is not clear, it is concerned with perception of sensation. Thus, the sensory parts of body have two representations, in somesthetic area I and area II.

■ SOMESTHETIC ASSOCIATION AREA

Somesthetic association area is situated posterior to postcentral gyrus, above the auditory cortex and in front of visual cortex. It has two areas, 5 and 7.

Functions of Somesthetic Association Area

Somesthetic association area is concerned with synthesis of various sensations perceived by somesthetic area I. Thus, the somesthetic association area forms the center for combined sensations like stereognosis. Lesion of this area causes astereognosis.

Sensory Motor Area

Sensory area of cortex is not limited to postcentral gyrus in parietal lobe. It extends anteriorly into motor area in precentral gyrus of frontal lobe. Similarly, the motor area is extended from precentral gyrus posteriorly into postcentral gyrus.

Thus, the precentral and postcentral gyri are knit together by association neurons and are functionally inter-related. So, this area is called sensory motor area.

Function of sensory motor area is to store the timing and programming of various sequential movements of complicated skilled movements, which are planned by neocerebellum (Table 152.2).

■ APPLIED PHYSIOLOGY

Lesion or ablation of parietal lobe (sensory cortex) results in the following disturbances:

1. Contralateral disturbance of cutaneous sensations
2. Disturbances in kinesthetic sensations
3. Loss of tactile localization and discrimination.

■ TEMPORAL LOBE

Temporal lobe of cerebral cortex includes three functional areas (Table 152.3):

A. Primary auditory area
B. Secondary auditory area or auditopsychic area
C. Area for equilibrium.

■ PRIMARY AUDITORY AREA

Primary auditory area includes:

1. Area 41
2. Area 42
3. Wernicke area.

TABLE 152.2: Areas and connections of parietal lobe

Areas	Afferent fibers from	Efferent fibers to
Somesthetic area I – 3, 1, 2 (Primary somesthetic area)	Thalamus	Premotor area
Somesthetic area II	Somesthetic area I Thalamus	Motor area
Somesthetic association areas 5, 7	Somesthetic area I	Somesthetic area I

TABLE 152.3: Areas and connections of temporal lobe

Areas	Afferent fibers from	Efferent fibers to
Primary auditory areas 41, 42, Wernicke area	1. Medial geniculate body via auditory radiation 2. Pulvinar	1. Medial geniculate body 2. Pulvinar
Auditopsychic area 22		
Area for equilibrium		

Areas 41 and 42 are situated in anterior transverse gyrus and lateral surface of superior temporal gyrus. Wernicke area is in upper part of superior temporal gyrus posterior to areas 41 and 42.

Connections of Primary Auditory Area

Afferent connections

Primary auditory are receives afferent fibers from:
1. Medial geniculate body via auditory radiation
2. Pulvinar of thalamus.

Efferent connections

This area sends efferent fibers to:
1. Medial geniculate body
2. Pulvinar.

Functions of Primary Auditory Area

Primary auditory area is concerned with perception of auditory impulses, analysis of pitch and determination of intensity and source of sound.

Areas 41 and 42 are concerned only with the **perception** of auditory sensation (sound). Wernicke area is responsible for the **interpretation** of auditory sensation. It carries out this function with the help of secondary auditory area (area 22). Wernicke area is also responsible for understanding the auditory information about any word and sending the information to Broca area (Chapter 162).

■ SECONDARY AUDITORY AREA

Secondary auditory area occupies the superior temporal gyrus. It is also called or **auditopsychic area** or **auditory association** area. It includes area 22.

This area is concerned with interpretation of auditory sensation along with Wernicke area. It is also concerned with storage of memories of spoken words (Chapter 162).

■ AREA FOR EQUILIBRIUM

Area for equilibrium is in the posterior part of superior temporal gyrus. It is concerned with the maintenance of equilibrium of the body. Stimulation of this area causes dizziness, swaying, falling and feeling of rotation.

■ APPLIED PHYSIOLOGY – TEMPORAL LOBE SYNDROME

Temporal lobe syndrome is otherwise known as **Kluver-Bucy syndrome.** It is observed in animals, particularly monkeys after the bilateral ablation of temporal lobe along with amygdala and uncus. It occurs in human beings during bilateral lesions of these structures.

Manifestations of this syndrome are:
1. **Aphasia** (disturbance in speech: Chapter 162)
2. Auditory disturbances such as frequent attacks of tinnitus, auditory hallucinations with sounds like buzzing, ringing or humming. **Tinnitus** means noise in the ear. **Hallucination** means feeling of a particular type of sensation without any stimulus.
3. Disturbances in smell and taste sensations
4. Dreamy states: The patients are not aware of their own activities and have the feeling of unreality
5. **Visual hallucinations** associated with hemianopia.

■ OCCIPITAL LOBE

Occipital lobe is called the **visual cortex.** Areas and connections of occipital lobe is given in Table 152.4.

TABLE 152.4: Areas and connections of occipital lobe

Areas	Afferent fibers from	Efferent fibers to
Primary visual area – 17	Lateral geniculate body	Superior colliculus Lateral geniculate body
Visual association area – 18		
Occipital eye field – 19		

■ AREAS OF VISUAL CORTEX

Occipital lobe consists of three functional areas:

1. Primary visual area (area 17)
2. Secondary visual area or visuopsychic area (area 18)
3. Occipital eye field (area 19).

Connections of Occipital Lobe

Occipital lobe receives afferent fibers from lateral geniculate body. It sends efferent fibers to superior colliculus and lateral geniculate body.

Functions of Occipital Lobe

1. Primary visual area (area 17) is concerned with **perception** of visual sensation
2. Secondary visual area (area 18) is concerned with **interpretation** of visual sensation and storage of memories of visual symbols (Chapter 162)
3. Occipital eye field (area 19) is concerned with reflex **movement of eyeballs.** It is also concerned with associated movements of eyeballs while following a moving object. (Table 152.5).

■ APPLIED PHYSIOLOGY

Lesion in the upper or lower part of visual cortex results in hemianopia. Bilateral lesion leads to total blindness. Refer Chapter 168 for details.

■ METHODS TO STUDY CORTICAL CONNECTIONS AND FUNCTIONS

■ BY CUTTING OR DESTRUCTION OF NERVE CELL

1. If the nerve cell body is destroyed, degenerative changes occur throughout the axon arising from it. By using **Marchi staining** technique, course of the nerve fiber could be traced. If any part of motor area is destroyed, the degeneration of the fibers in the pyramidal tracts can be traced. If arm fibers are involved, the degeneration occurs up to lower cervical and upper thoracic level.
2. If an axon is cut, the nerve cell body (from which the axon arises) undergoes **chromatolysis**. If any fiber in pyramidal tract is cut, the chromatolysis occurs in nerve cell body situated in motor cortex.

Thus, this method is used to study connections and localization in motor cortex. It is also used for the study of connections of different parts of cerebral cortex.

■ BY RECORDING ELECTRICAL ACTIVITY – EVOKED POTENTIAL

When an impulse passes through a nerve, its route and the termination can be determined by recording the electrical potentials using microelectrodes at different points along the course of the nerve fiber. This method is used to trace certain pathways from or to the cortex, particularly auditory pathway and pyramidal tract.

Evoked Potential

Evoked potential is the electrical potential or electrical response in a neuron or group of neurons in the brain produced by an external stimulus. It is also called **evoked cortical potential.**

When any receptor of skin or a sense organ (eye or ear) is stimulated, the impulses pass through the afferents and reach cerebral cortex. By using scalp electrodes, the potentials developed in cortical areas can be recorded. This method is used to determine the functions of various cortical areas. It is also used to map out the cortical representation of body (localization) for sensory function.

Evoked potential is recorded by placing the exploring electrode on the surface of the head over the primary cortical area of the particular sensation. Indifferent electrode is placed on a distant area of head. In human beings small disk like electrodes are placed on different areas of head by using a tape or washable paste. Electrode cap, which is placed over the head can also be used.

Analysis and interpretation of the potential is done by computer. Evoked potential is characterized by two types of response.

TABLE 152.5: Functions of cortical lobes

Lobe				Functions
Frontal lobe	Precentral cortex	Primary motor area	Area 4	Initiates of movements
			Area 4S	Inhibits exaggeration of movements initiated by area 4
		Premotor area	Area 6	Coordinates movements initiated by area 4 Acts as higher center for extrapyramidal system
			Area 8	Frontal eye field Concerned with conjugate movements of eyeballs Concerned with voluntary movements of eyeballs
			Broca area: Areas 44 and 45	Initiates movements involved in speech; motor speech area
		Supplementary motor area	–	Concerned with coordinated skilled movements
	Prefrontal cortex	Areas 9, 10, 11, 12, 13, 14, 23, 24, 29 and 32		Concerned with emotion, learning, memory and social behavior Act as the center for planned actions Form seat of intelligence Initiate autonomic changes during emotional conditions
Parietal lobe	Somesthetic area I	Area 1		Perceives cutaneous and kinesthetic sensations
		Areas 3 and 2		Integrate cutaneous and kinesthetic sensations
		Areas 3, 2 and 1		Send feedback to premotor area Concerned with movements of head and eyeballs Concerned with recognition of discriminative features of sensations
	Somesthetic area II	–		Perceives cutaneous and kinesthetic sensations
	Somesthetic association area	Areas 5 and 7		Synthesize sensations perceived by somesthetic area I (forms the center for combined sensations)
Temporal lobe	Primary auditory area	Areas 41 and 42		Perceive auditory sensation
		Wernicke area		Interprets auditory sensation (along with area 22)
	Secondary auditory area	Area 22		Interprets auditory sensation (along with Wernicke area)
	Area for equilibrium	–		Concerned with maintenance of equilibrium of body
Occipital lobe	Primary visual area	Area 17		Perceives visual sensation
	Secondary visual area	Area 18		Interprets visual sensation
	Occipital eye field	Area 19		Concerned with reflex movement of eyeballs Concerned with associated movements of eyeballs while following a moving object

1. *Primary evoked potential*

When the stimulus is applied to the receptor or sense organ, the primary evoked potential appears after a latent period of 5 to 10 milliseconds. It includes a positive wave followed by a small negative wave. Primary evoked potential is highly localized and appears specifically on the cortical surface where the particular sensory pathway terminates.

2. *Diffuse secondary evoked potential*

Finally another larger and prolonged positive wave called secondary evoked potential is recorded. It is not localized. It appears on the diffused areas of cortex.

Thus, the evoked potential includes P1-N1-P2 sequence, i.e. first positive wave – first negative wave – second positive wave.

Diagnostic Uses of Evoked Potential

An evoked potential test determines the functional status of a nervous pathway. It also measures the time taken by the nerves to respond to stimulation. Intensity of response is also measured. Nerves from different areas of the body may be tested. However, three types of evoked potentials are commonly used in diagnosis.

1. **Visual evoked potential,** which is recorded when the visual receptors are stimulated by looking at a test pattern
2. **Auditory evoked potential** that is recorded when auditory receptors are stimulated by listening to a test sound
3. **Somatosensory evoked potential,** which is recorded when the somatic nerves of the limbs are stimulated by electrical stimulus.

■ BY PHYSIOLOGICAL NEURONOGRAPHY

When a small piece of blotting paper soaked in **strychnine** solution is placed over cerebral cortex, the nerve cells are stimulated by strychnine. The impulses discharged by these nerve cells pass through the axons and reach the termination in other part of cortex or other part of brain. By recording these impulses, the connections of cortex can be studied.

■ BY SCANNING

Nowadays, the functional activities of cerebral cortex or other parts of the brain are determined by scanning. Due to the fast development of technology, many sophisticated scanning methods are being introduced. Three such methods used widely are:

1. Computerized axial tomography (CAT)
2. Positron emission tomography (PET)
3. Magnetic resonance imaging (MRI).

Refer Chapter 109 for details of these scanning methods.

Limbic System

Chapter 153

- INTRODUCTION
- COMPONENTS
  - ARCHICORTICAL STRUCTURES
  - PALEOCORTICAL STRUCTURES
  - JUXTALLOCORTICAL STRUCTURES
  - SUBCORTICAL STRUCTURES
- CONNECTIONS
- FUNCTIONS
  - OLFACTION
  - REGULATION OF ENDOCRINE GLANDS
  - REGULATION OF AUTONOMIC FUNCTIONS
  - REGULATION OF FOOD INTAKE
  - CONTROL OF CIRCADIAN RHYTHM
  - REGULATION OF SEXUAL FUNCTION
  - ROLE IN EMOTIONAL STATE
  - ROLE IN MEMORY
  - ROLE IN MOTIVATION

INTRODUCTION

Limbic system is a complex system of cortical and subcortical structures that form a **ring** around the hilus of cerebral hemisphere. **Limbus** means ring. It is also known as **limbic lobe.** Earlier, it was called **rhinencephalon.**

In terms of evolutionary development **(phylogeny),** limbic system is one of the oldest parts of the brain and it is related to olfactory lobe. It is found as a prominent structure in fish, amphibians, reptiles and mammals.

Limbic system is primarily related to emotional part of our life and is extensively concerned with memory.

COMPONENTS OF LIMBIC SYSTEM

Structures of limbic system are classified into four groups (Fig. 153.1):

1. Archicortical structures
2. Paleocortical structures
3. Juxtallocortical structures
4. Subcortical structures.

ARCHICORTICAL STRUCTURES

Archicortex forms **allocortex** along with **paleocortex** (Chapter 152). Archicortex is the phylogenetically oldest structure. It is concerned with **memory.**

PALEOCORTICAL STRUCTURES

Paleocortex is in between archicortex and neocortex. It is concerned with **olfaction.**

JUXTALLOCORTICAL STRUCTURES

Juxtallocortex or **mesocortex** is situated between paleocortex and neocortex.

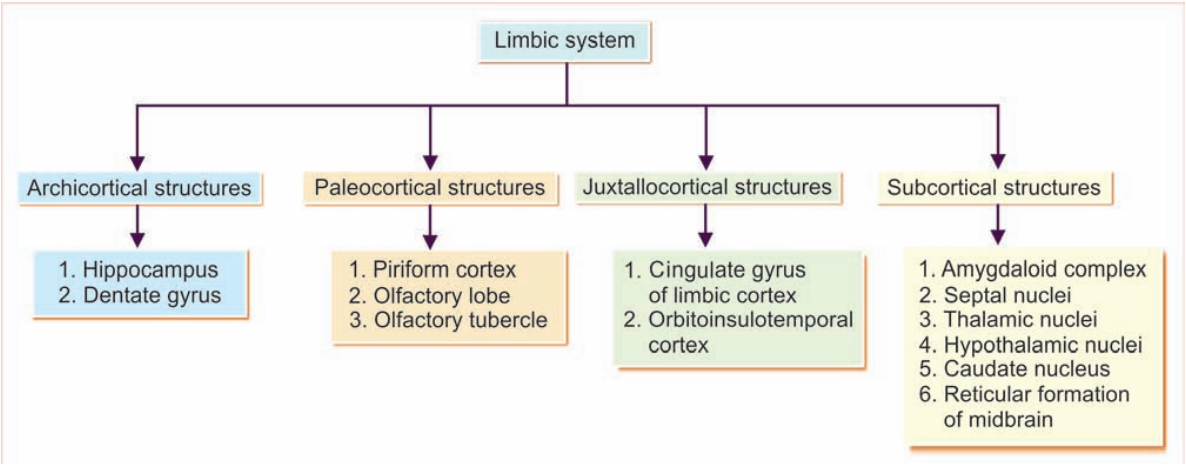

FIGURE 153.1: Components of limbic system

■ SUBCORTICAL STRUCTURES

Structures situated below the level of cortex are called subcortical structures. Limbic system includes six subcortical structures (Figs. 153.1 and 153.2).

■ CONNECTIONS OF LIMBIC SYSTEM

Connections of limbic system are complex. Following are the major (afferent and efferent) connections of limbic system:

1. Fornix: It includes fibers connecting:
   i. Hippocampus and septal nuclei with the mamillary body
   ii. Hippocampus with hypothalamic nuclei.
2. Lateral hypothalamus receives afferent fibers from:
   i. Hippocampus
   ii. Septal nuclei
   iii. Olfactory tubercle
   iv. Head of caudate nucleus
   v. Piriform area
   vi. Periamygdaloid area.
3. Caudate nucleus receives fibers from:
   i. Cingulate gyrus
   ii. Intralaminar nuclei of thalamus.
4. Brainstem reticular formation receives fibers from:
   i. Hippocampus
   ii. Cingulate gyrus.
5. Papez circuit.

Papez Circuit

Papez circuit is the interconnections between various structures of limbic system, which form a complex of closed circuit. This circuit was described by Papez.

Hippocampus is connected to mamillary bodies of hypothalamus via fornix. Mamillary bodies are connected to anterior thalamic nucleus via mamillothalamic tract. Anterior thalamic nucleus is projected into cingulate gyrus through medial thalamocortical fibers. Cingulate gyrus is in turn connected to hippocampus (Fig. 153.3). Papez circuit plays a role in **memory encoding** (Chapter 162).

■ FUNCTIONS OF LIMBIC SYSTEM

■ 1. OLFACTION

Piriform cortex and amygdaloid nucleus form the **olfactory centers.** In lower animals, the amygdaloid nucleus is concerned primarily with olfaction.

■ 2. REGULATION OF ENDOCRINE GLANDS

Hypothalamus plays an important role in regulation of endocrine secretion (Chapter 66).

■ 3. REGULATION OF AUTONOMIC FUNCTIONS

Hypothalamus plays an important role in regulating the autonomic functions (Chapter 149) such as:

i. Heart rate
ii. Blood pressure

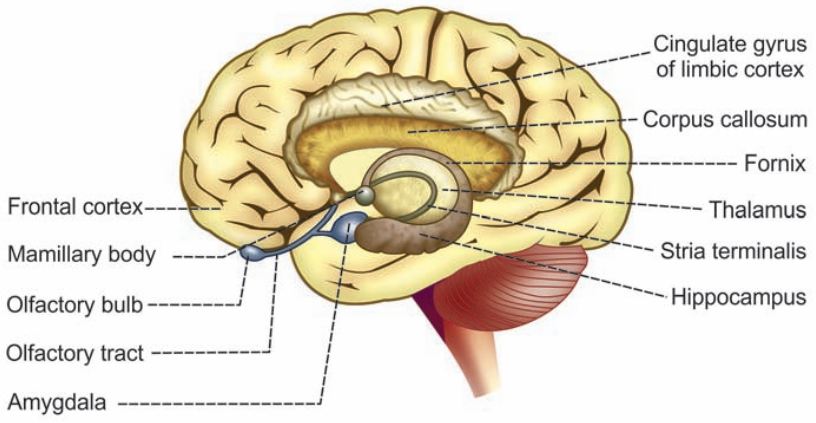

FIGURE 153.2: Major components of limbic system

iii. Water balance
iv. Body temperature.

■ 4. REGULATION OF FOOD INTAKE

Along with amygdaloid complex, the feeding center and satiety center present in hypothalamus regulate food intake (Chapter 149).

■ 5. CONTROL OF CIRCADIAN RHYTHM

Hypothalamus is taking major role in the circadian fluctuations of various physiological activities (Chapter 149).

■ 6. REGULATION OF SEXUAL FUNCTIONS

Hypothalamus is responsible for maintaining sexual functions in both man and animals (Chapter 149).

■ 7. ROLE IN EMOTIONAL STATE

Emotional state of human beings is maintained by hippocampus along with hypothalamus (Chapter 149).

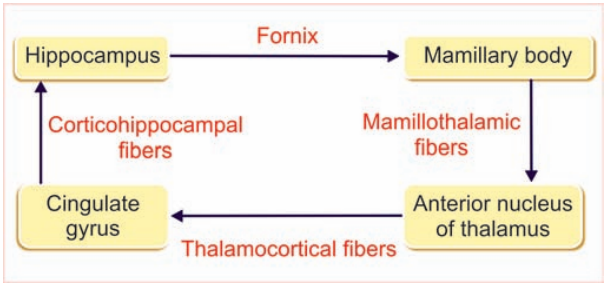

FIGURE 153.3: Papez circuit

■ 8. ROLE IN MEMORY

Hippocampus and Papez circuit play an important role in memory (Chapter 162).

■ 9. ROLE IN MOTIVATION

Reward and punishment centers present in hypothalamus and other structures of limbic system are responsible for motivation and the behavior pattern of human beings (Chapter 149).

Refer Chapter 149 for details of the hypothalamic functions.

Reticular Formation

Chapter 154

- DEFINITION
- SITUATION
- ORGANIZATION OF RETICULAR FORMATION
  - RAPHE GROUP
  - PARAMEDIAN GROUP
  - LATERAL GROUP
  - MEDIAL GROUP
  - INTERMEDIATE GROUP
- DIVISIONS OF RETICULAR FORMATION
  - NUCLEI OF MEDULLARY RETICULAR FORMATION
  - NUCLEI OF PONTINE RETICULAR FORMATION
  - NUCLEI OF MIDBRAIN RETICULAR FORMATION
- CONNECTIONS
  - AFFERENT CONNECTIONS
  - EFFERENT CONNECTIONS
- FUNCTIONS
  - ASCENDING RETICULAR ACTIVATING SYSTEM (ARAS)
  - DESCENDING RETICULAR SYSTEM

DEFINITION

Reticular formation is a diffused mass of neurons and nerve fibers, which form an ill-defined meshwork of reticulum in central portion of the brainstem.

SITUATION OF RETICULAR FORMATION

Reticular formation is situated in **brainstem.** It extends downwards into spinal cord and upwards up to thalamus and subthalamus.

ORGANIZATION OF RETICULAR FORMATION

Reticular formation is constituted by 5 groups of nuclei. All these nuclei are structurally and functionally distinct.

1. RAPHE GROUP

Raphe group of nuclei are situated along the midline of the brainstem forming a continuous column. Raphe nuclei secrete **serotonin** (5-hydroxytryptamine), which is an **inhibitory neurotransmitter.**

2. PARAMEDIAN GROUP

Paramedian group includes nucleus reticularis para-medianus and pontine reticulotegmental nucleus. These nuclei are concerned with **motor functions.**

3. LATERAL GROUP

Lateral group of nuclei are situated in the lateral one third of the tegmentum. It consists of nuclei with small (parvocellular) cells. Neurons of these nuclei receive sensory signals from the cranial nerves, cerebellum and spinal cord.

4. MEDIAL GROUP

Medial group of nuclei are situated in the medial two third of the tegmentum. It consists of nuclei with small cells and giant (gigantocellular) cells. Nuclei of this group form the major output of the reticular formation and send fibers to the hypothalamus, thalamus and spinal cord. These nuclei are associated with **motor functions.**

5. INTERMEDIATE GROUP

Intermediate group of nuclei are present only in the medulla. It is situated between the lateral and medial groups of nuclei. These nuclei are concerned with autonomic regulation of **respiration, heart rate** and **blood pressure.**

DIVISIONS OF RETICULAR FORMATION

Reticular formation is divided into three divisions based on the location in brainstem:

A. Medullary reticular formation
B. Pontine reticular formation
C. Midbrain reticular formation.

Each division of reticular formation has its own collection of nuclei.

NUCLEI OF MEDULLARY RETICULAR FORMATION

1. Lateral reticular nucleus
2. Ventral reticular nucleus
3. Dorsal reticular nucleus
4. Gigantocellular reticular nucleus
5. Paragigantocellular reticular nucleus
6. Paramedian reticular nucleus
7. Parvocellular reticular nucleus
8. Magnocellular reticular nucleus.

NUCLEI OF PONTINE RETICULAR FORMATION

1. Nucleus reticularis pontis oralis
2. Nucleus reticularis pontis caudalis
3. Locus ceruleus nucleus
4. Subceruleus reticular nucleus
5. Tegmenti pontis reticular nucleus
6. Pedunculopontine reticular nucleus
7. Nucleus reticular cuneiformis.

NUCLEI OF MIDBRAIN RETICULAR FORMATION

1. Red nucleus
2. Nucleus tegmental pedunculopontis
3. Nucleus reticular subcuneiformis.

CONNECTIONS OF RETICULAR FORMATION

AFFERENT CONNECTIONS

Reticular formation receives collaterals from almost all the ascending sensory pathways. It also receives fibers from different parts of the brain (Fig. 154.1):

1. Optic pathway
2. Olfactory pathway
3. Auditory pathway
4. Taste pathway
5. Spinal and trigeminal pathways carrying touch sensation
6. Pathways for pain, temperature, vibration and kinesthetic sensations
7. Cerebral cortex
8. Cerebellum
9. Corpus striatum
10. Thalamic nuclei.

EFFERENT CONNECTIONS

Reticular formation sends fibers to the following parts of central nervous system (Fig. 154.2):

1. Cerebral cortex
2. Diencephalon: Thalamus, hypothalamus and subthalamus

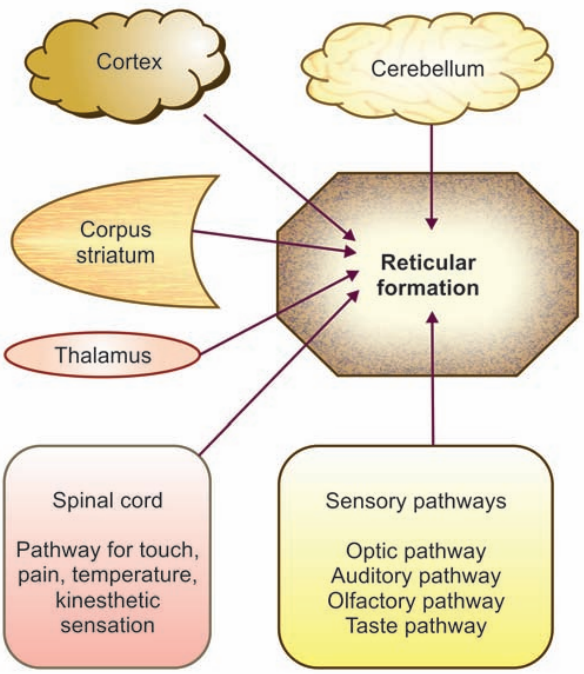

FIGURE 154.1: Afferent connections of reticular formation

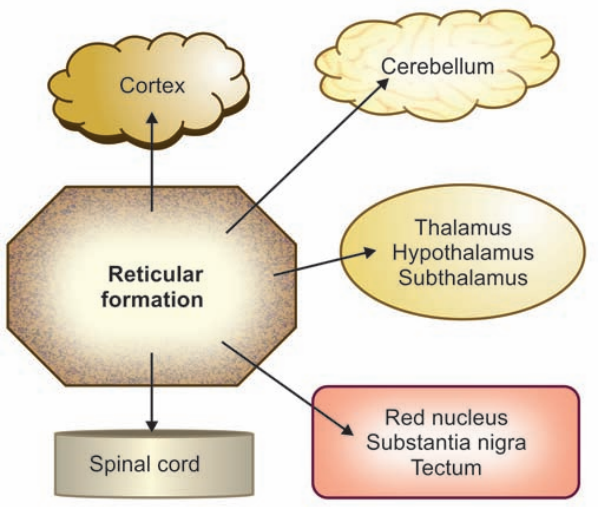

FIGURE 154.2: Efferent connections of reticular formation

3. Midbrain: Red nucleus, tectum and substantia nigra
4. Cerebellum
5. Spinal cord.

FUNCTIONS OF RETICULAR FORMATION

Based on functions, reticular formation along with its connections is divided into two systems:

A. Ascending reticular activating system
B. Descending reticular system.

ASCENDING RETICULAR ACTIVATING SYSTEM

Ascending reticular activating system **(ARAS)** begins in lower part of brainstem, extends upwards through pons, midbrain, thalamus and finally projects throughout the cerebral cortex. It projects into cerebral cortex in two ways:

1. Via subthalamus
2. Via thalamus.

The ARAS receives fibers from the sensory pathways via long ascending spinal tracts (Fig. 154.3).

Functions of ARAS

1. The ARAS is concerned with **arousal** phenomenon, **alertness,** maintenance of **attention** and **wakefulness.** Hence, it is called ascending reticular activating system. Stimulation of midbrain reticular formation produces wakefulness by **generalized activation** of entire brain including cerebral cortex, thalamus, basal ganglia and brainstem.

   Any type of sensory impulses such as impulses of proprioception, pain, auditory, visual, taste and olfactory sensations cause sudden activation of the ARAS producing arousal phenomenon in animals and human beings. Even the impulses of visceral sensations activate this system. Sympathetic stimulation and adrenaline cause arousal by affecting midbrain.
2. The ARAS also causes **emotional reactions**
3. The ARAS plays an important role in regulating the **learning processes** and the development of **conditioned reflexes.**

Mechanism of Action of ARAS

Impulses of all the sensations reach cerebral cortex through two channels:

1. Classical sensory pathways
2. Ascending reticular activating system.

1. *Classical or specific sensory pathways*

Classical sensory pathways are the pathways, which transmit the sensory impulses from receptors to cerebral cortex via thalamus. Some of the pathways carry impulses of a particular sensation only. For example, auditory stimulus transmitted by auditory pathway reaches the auditory cortex via thalamus and causes perception of sound. Such classical sensory pathways are called specific sensory pathways.

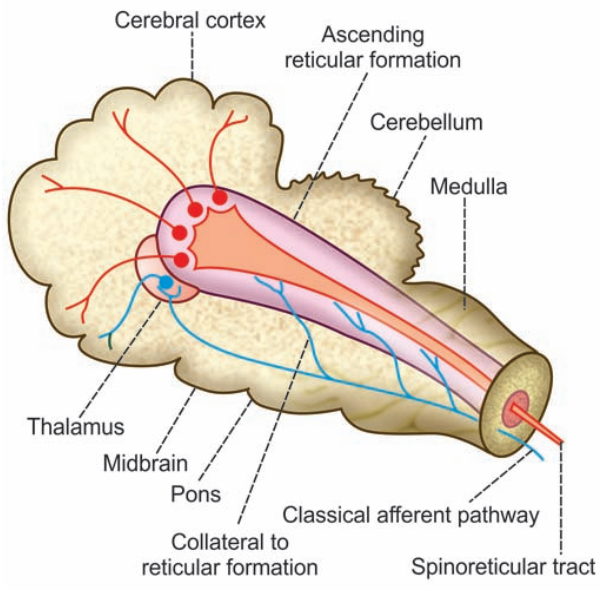

FIGURE 154.3: Ascending reticular formation

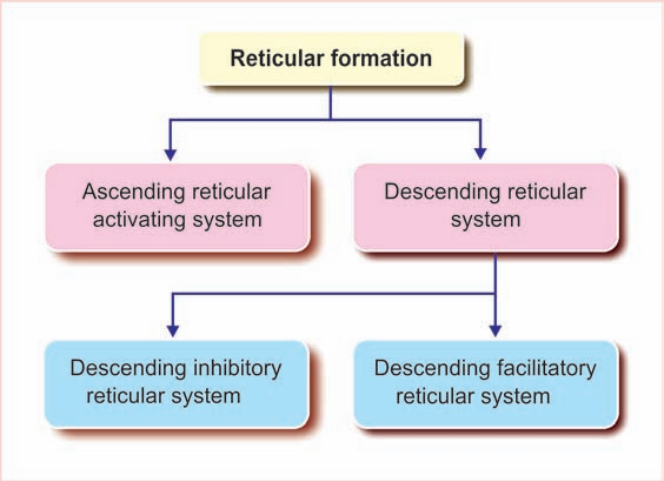

FIGURE 154.4: Functional divisions of reticular formation

2. Ascending reticular activating system or non-specific sensory pathway

All the sensory pathways send collaterals to ARAS, which is a multisynaptic relay system. These collaterals project in diffused areas of ARAS. So, the sensory impulses transmitted via the collaterals reach different parts of ARAS. It also receives afferents from spinal cord directly in the form of spinoreticular tract. ARAS in turn sends the impulses to almost all the areas of cerebral cortex and other parts of brain. Hence, this pathway is called the non-specific sensory pathway.

Non-specific projection of ARAS into the cortex is responsible for the arousal, alertness and wakefulness. Sensory impulses transmitted directly to cortex via classical pathway causes perception of only the particular sensation. Whereas, the impulses transmitted to cortex via ARAS do not cause the perception of any particular sensation, but cause the generalized activation of almost all the areas of cerebral cortex and other parts of brain. This leads to reactions of arousal, alertness and wakefulness.

The ARAS is in turn controlled by the feedback signals from cerebral cortex. Also, an inhibitory system controls the activities of ARAS. Inhibitory system involves posterior hypothalamus, intralaminar and anterior thalamic nuclei and medullary area at the level of tractus solitarius.

Tumor or lesion in ARAS leads to **sleeping sickness** or **coma.** The impact of head injury on ARAS also causes coma.

■ DESCENDING RETICULAR SYSTEM

Descending reticular system includes reticular formation in brainstem, reticulospinal tract and reticular formation in spiral cord.

It modifies the activities of spinal motor neurons. Functionally, descending reticular system is divided into two subdivisions (Fig. 154.4):

1. Descending facilitatory reticular system
2. Descending inhibitory reticular system.

Descending Facilitatory Reticular System

Descending facilitatory reticular system is present in upper and lateral reticular formation. Its functions are:

i. *Facilitation of somatomotor activities*

a. Descending facilitatory reticular system maintains muscle tone by exciting the gamma motor neurons in spinal cord; stimulation of this area causes increased muscle tone
b. It facilitates the movements of the body. Stimulation of this part of reticular system causes exaggerated movements.
c. It plays a role in wakefulness and alertness by activating the ARAS.

ii. *Facilitation of vegetative functions*

Descending facilitatory reticular system is the center for facilitation of the autonomic functions such as cardiac function, blood pressure, respiration, gastrointestinal function and body temperature.

Descending Inhibitory Reticular System

Descending inhibitory reticular system is located in a small area in lower and medial reticular formation. Its functions are:

i. *Control of somatomotor activities*

a. Descending inhibitory reticular system plays an important role in the control of muscle tone. By receiving signals from basal ganglia, it inhibits the gamma motor neurons of spinal cord and decreases muscle tone. Stimulation of this area causes decreased muscle tone.

b. It is responsible for smoothness and accuracy of voluntary movements. It controls the muscular activity by inhibiting the motor neurons of spinal cord.

c. It also controls the reflex movements.

ii. *Control of vegetative functions*

Descending inhibitory reticular system is the center for inhibition of several autonomic functions such as cardiac function, blood pressure, respiration, gastrointestinal function and body temperature.

Preparations of Animals for Experimental Studies

Chapter 155

- INTRODUCTION
- DECORTICATE PREPARATION
- DECEREBRATE PREPARATION
- THALAMIC (MIDBRAIN) PREPARATION
- SPINAL PREPARATION

INTRODUCTION

Various functions of nervous system, particularly the maintenance of posture and equilibrium are studied by observing the effects of sections or lesions at different levels of central nervous system in animals. Commonly used animals are monkeys, dogs and cats.

DECORTICATE PREPARATION

Decorticate animal is the one **without cerebral cortex.** It is prepared by removing whole cerebral cortex leaving basal ganglia intact. It is also prepared by removing all the connections of cerebral cortex.

Effect of decortication varies with species and the conditions under which the animal is being examined.

In a dog or cat, when the animal is on its feet, posture is normal. Muscle tone is normally distributed and it is present equally in flexor and extensor muscles. Movements during walking can be performed by reflex activity. If the animal is suspended in the air, there is severe hyperextension of all the limbs. In decorticate monkey, the tone is gravely affected. Movements of walking cannot occur by reflex activity.

Effects in Man

In man, decorticate condition is caused by intracranial hemorrhage, head injury, brain abscess or brain tumor. Decorticate condition is called decorticate rigidity.

Decorticate Rigidity

Decorticate rigidity is the abnormal postural changes that involve rigid extension of the lower limbs and flexion of the upper limbs at elbow joint across the chest. Wrists and fingers are also flexed. Posture may develop on one side or both sides of the body.

Effects on Reflexes

Reflexes at the neck level can be elicited. These neck reflexes affect the body also. When the neck is turned to right, there is flexion of the lower and upper limbs on the opposite side. But, on the same side, there is extension of the limbs. It may be due to the cutting or lesion of direct corticospinal tract. Some fibers of corticospinal tract are known to have inhibitory influence on the extensor muscles.

DECEREBRATE PREPARATION

It is prepared by removing all **connections of cerebral hemispheres** at the level of midbrain, by sectioning in between the superior colliculus and inferior colliculus. This preparation is characterized by a state of stiffness or rigidity, which is known as **decerebrate rigidity,** resembling the effects of upper motor neuron lesion. This preparation was first done by Nobel laureate, **Sir Charles Sherrington** in cat.

Decerebrate Rigidity

Decerebrate rigidity is the rigid extension of all the limbs due to decerebration. This type of rigidity is well pronounced in the extensor muscles. The term decerebrate rigidity was coined by Sherrington in 1897.

Reason for decerebrate rigidity is the release of the centers, situated below the section, from higher inhibitory controls. The inhibitory area is 4S. It is situated in the motor cortex of cerebrum, just anterior to area 4 and behind area 6. In this area, Betz cells are absent. From here, the fibers are projected to spinal cord via reticular formation. So in decerebration the discharge from neurons of area 4S cannot reach spinal motor neurons. This leads to exaggeration of spinal motor neurons resulting in rigidity.

Decerebrate rigidity is also produced by stopping the blood flow to the forebrain. It is done by occlusion of the common carotid artery and the basilar artery at the center of the pons.

Opisthotonos

In decerebrate animal, the caricature or characteristic posture is the extension of all the four limbs, extension of the tail and arching of the back or hyperextension of the spine. This type of attitude of the animal is called opisthotonos. The animal can stand but, if disturbed, the posture cannot be maintained.

Decerebration in Man

In man, decerebration occurs due to lesion in diencephalon or midbrain.

■ THALAMIC (MIDBRAIN) PREPARATION

In thalamic animal, all the **connections of thalamus** with cerebral cortex are removed by sectioning at the superior border of midbrain. All the fine sensations such as fine touch, tactile discrimination and tactile localization are lost. The conscious kinesthetic sensation is also lost. But, the crude touch, pressure, pain and temperature sensations remain intact.

Righting reflexes are retained. The muscle tone is not affected. Rigidity is absent. But when the animal is held in air, extensor rigidity develops. Coordination of the reflex movements is not lost. However, the exaggeration of movements occurs during emotional states. Abnormal involuntary movements are absent.

■ SPINAL PREPARATION

Complete transection of spinal cord is called spinal preparation. Immediate effect of complete transection of spinal cord is the spinal shock. The animal recovers from the shock after some time. Tone is returned to the flexor muscles. Extensor muscles do not regain the tone or regain it after some time and these muscles attain the flaccidity. It is because the facilitatory impulses from reticular formation are cut off in spinal preparation. Effects of complete transection of spinal cord are given in Chapter 143.

Chapter 156

Proprioceptors

- PROPRIOCEPTORS
- MUSCLE SPINDLE
  - STRUCTURE
  - NERVE SUPPLY
  - FUNCTIONS
- GOLGI TENDON ORGAN
  - STRUCTURE
  - NERVE SUPPLY
  - FUNCTIONS
- PACINIAN CORPUSCLE
- FREE NERVE ENDING

PROPRIOCEPTORS

It is necessary to know about the proprioceptors to understand the maintenance of posture and equilibrium, which is explained in the next chapter.

Definition

Proprioceptors are the receptors, which detect and give response to movement and change in position of different parts of the body. These receptors are also called **kinesthetic receptors.**

Situation

Proprioceptors are situated in labyrinth, muscles, tendon of the muscles, joints, ligaments and fascia (Table 156.1).

Different Proprioceptors

1. Muscle spindle
2. Golgi tendon organ
3. Pacinian corpuscle
4. Free nerve ending
5. Proprioceptors in labyrinth.

Proprioceptors in the labyrinth are described in Chapter 158.

TABLE 156.1: Situation of proprioceptors

Proprioceptor	Situation
Muscle spindle	Skeletal muscles
Golgi tendon organ	Tendons
Pacinian corpuscle	Skin Fascia over muscles Tendons Tissues around joint Joint capsule
Free nerve ending	Skin Skeletal muscles Tendons Fascia over muscles Joints
Labyrinthine proprioceptors	Labyrinth

MUSCLE SPINDLE

Muscle spindle is a spindle-shaped **proprioceptor** situated in the skeletal muscle. It is formed by modified skeletal muscle fibers called **intrafusal muscle fibers.**

STRUCTURE OF MUSCLE SPINDLE

Muscle spindle has a central bulged portion and two tapering ends. Each muscle spindle is formed by 5 to 12

intrafusal muscle fibers. All these fibers are enclosed by a capsule, which is formed by connective tissue. Intrafusal fibers are attached to the capsule on either end. The capsule is attached to either side of extrafusal fibers or the tendon of the muscle. Thus, intrafusal fibers are placed parallel to the extrafusal fibers. Intrafusal fibers are thin and striated (Fig. 156.1).

Central portion of the intrafusal fibers does not contract because it has only few or no actin and myosin filaments. So, this portion acts only as a receptor. Only the end portion of intrafusal fibers can contract. The discharge from gamma motor neurons causes the contraction of intrafusal fibers.

Types of Intrafusal Fibers

Muscle spindle is formed by two types of intrafusal fibers:

1. Nuclear bag fiber
2. Nuclear chain fiber.

1. *Nuclear bag fiber*

Central portion of this fiber is enlarged like a **bag** and contains many nuclei. Hence, it is called the nuclear bag fiber.

2. *Nuclear chain fiber*

In nuclear chain fiber, central portion is not bulged and the nuclei are arranged in the center in the form of a chain. Nuclear chain fiber is attached to the side of end portion of nuclear bag fiber.

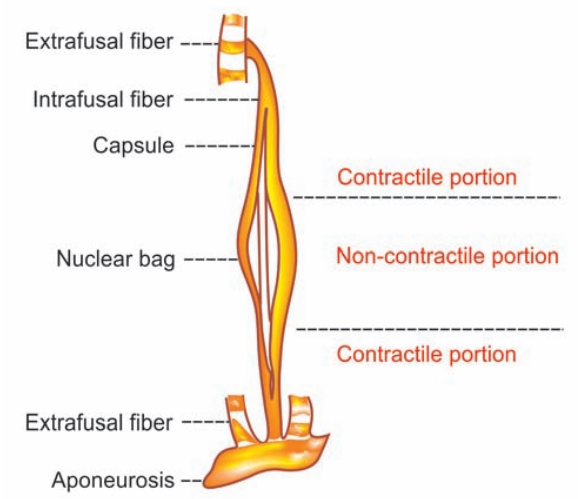

FIGURE 156.1: Muscle spindle

■ NERVE SUPPLY TO MUSCLE SPINDLE

Muscle spindle is innervated by both sensory and motor nerves. It is the **only receptor** in the body, which has both **sensory** and **motor nerve supply.**

Sensory Nerve Supply

Each muscle spindle receives two types of sensory nerve fibers:

1. Primary sensory nerve fiber
2. Secondary sensory nerve fiber.

1. Primary sensory nerve fiber

Primary sensory nerve fiber belongs to **type Iα (Aα)** nerve fiber. Each sensory (afferent) nerve fiber has two branches. One of the branches supplies the central portion of nuclear bag fiber (Fig. 156.2). The other branch ends in central portion of the nuclear chain fiber. These branches end in the form of rings around central portion of nuclear bag and nuclear chain fibers. Therefore, these nerve endings are called **annulospiral endings.**

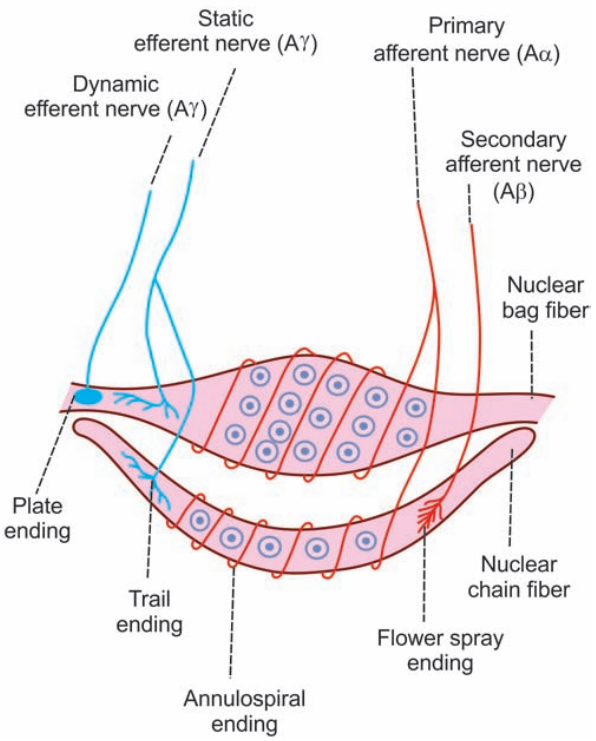

FIGURE 156.2: Nerve supply to muscle spindle. Red = Afferent (sensory) nerve fibers, Blue = Efferent (motor) nerve fibers. Letters in parenthesis indicate the type of nerve fibers.

2. *Secondary sensory nerve fiber*

Secondary sensory nerve fiber is a **type II (Aβ)** nerve fiber. It innervates only the nuclear chain fiber and ends near the end portion of nuclear chain fiber like the petals of the flower. So, this nerve ending is called **flower spray ending.**

Motor Nerve Supply

Motor (efferent) nerve fiber supplying the muscle spindle belongs to gamma motor neuron **(Aγ) type.**

Motor nerve supply to nuclear bag fiber

Gamma motor nerve fiber supplying the nuclear bag fiber ends as motor end plate. This nerve ending is called **plate ending.** Functionally, it is known as **dynamic gamma efferent** (motor) nerve fiber.

Motor nerve supply to nuclear chain fiber

Gamma motor nerve fiber supplying the nuclear chain fiber divides into many branches, which form a network called **trail ending.** Functionally, it is known as **static gamma efferent** (motor) nerve fiber. Sometimes, it gives a branch to nuclear bag fiber also.

■ FUNCTIONS OF MUSCLE SPINDLE

Muscle spindle gives response to change in the length of the muscle. It detects how much the muscle is being stretched and sends this information to central nervous system (CNS) via sensory nerve fibers. The information is processed in CNS to determine the position of different parts of the body. By detecting the change in length of the muscle, the spindle plays an important role in preventing the overstretching of the muscles.

Muscle spindle has two functions:

1. It forms the receptor organ for stretch reflex
2. It plays an important role in maintaining muscle tone.

1. *Role of Muscle Spindle in Stretch Reflex*

Stretch reflex

Stretch reflex is the reflex contraction of muscle when it is stretched. It is also called **myotatic reflex.** It is a **monosynaptic reflex** and the quickest of all the reflexes. Extensor muscles, particularly the antigravity muscles exhibit a severe and prolonged contraction during stretch reflex. Stretch reflex plays an important role in maintaining posture.

Muscle spindle as the receptor organ for stretch reflex

Stimulation of muscle spindle elicits the stretch reflex. Intrafusal muscle fibers are situated parallel to the extrafusal muscle fibers and are attached to the tendon of the muscle by means of capsule. So, stretching of the muscle causes **stretching of the muscle spindle** also. This stimulates the muscle spindle and it discharges the sensory impulses. These impulses are transmitted via the primary and secondary sensory nerve fibers to the alpha motor neurons in spinal cord. Alpha motor neurons in turn send motor impulse to muscles through their fibers and cause contraction of extrafusal fibers (Fig. 156.3).

Response of muscle spindle to stretch

When the muscle is stretched, primary sensory nerve fibers from muscle spindle discharge impulses. This response is of two types:

i. Dynamic response
ii. Static response.

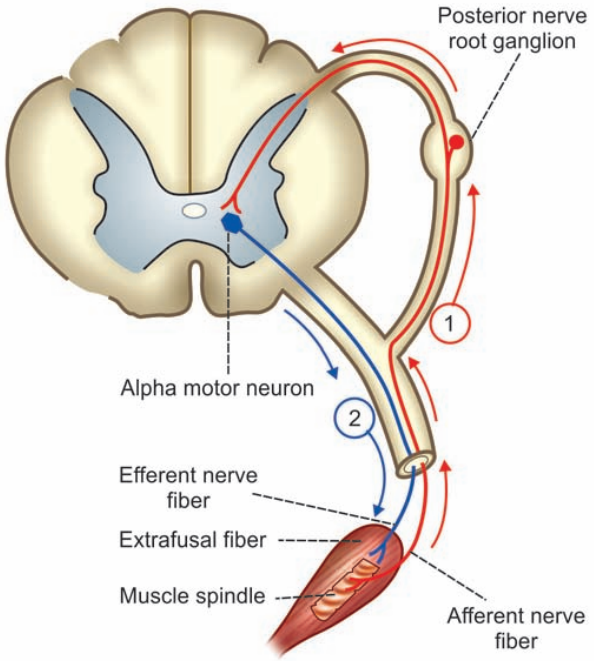

FIGURE 156.3: Stretch reflex. 1. Afferent impulses from muscle spindle of stretched muscle. 2. Efferent impulses from α-motor neurons causing contraction of muscle.

i. *Dynamic response*

Dynamic response is the response in which the primary sensory nerve fibers discharge rapidly. When there is a change in length of the muscle by stretching, primary sensory nerve fibers from nuclear bag fiber start discharging impulses very rapidly. But, the discharge becomes less or nil during continuous stretching of the muscle. Discharge of impulses start only if there is change in degree of stretching of the muscle. Thus, the response depends upon rate of change in length of the muscle.

ii. *Static response*

Static response is the response in which impulses are discharged rapidly and continuously throughout the period of muscle stretch by primary sensory nerve fibers of the nuclear chain fibers.

Thus, the muscle spindle gives response to change in length of the muscle as well as rate of change in length.

Physiologic tremor

Physiologic tremor is the continuous discharge of actions potentials with low voltage and ineffective frequency from primary and secondary sensory nerve fibers of muscle spindle at resting condition. Physiological tremor plays an important role in the feedback regulation of muscle length.

2. *Role of Muscle Spindle in the Maintenance of Muscle Tone*

The state of continuous and partial contraction of the muscle is called muscle tone (Chapter 157). It is due to the continuous discharge of impulses from gamma motor neurons.

Gamma motor neurons innervate the intrafusal fibers. Motor impulses from gamma motor neurons stimulate the intrafusal fibers of muscle spindle, which in turn sends sensory impulses back to spinal cord. Now the alpha motor neurons in spinal cord are activated resulting in contraction of extrafusal fibers of muscle. Refer Chapter 157 for details of this process. When the frequency of discharge from gamma motor neurons increases, activity of muscle spindle is increased and the muscle tone also increases.

GOLGI TENDON ORGAN

STRUCTURE OF GOLGI TENDON ORGAN

Golgi tendon organ is situated in the **tendon** of skeletal muscle near the attachment of extrafusal fibers. It is placed in series between the muscle fibers and the tendon. Golgi tendon organ is formed by a group of nerve endings covered by a connective tissue capsule (Fig. 156.4).

NERVE SUPPLY TO GOLGI TENDON ORGAN

Sensory nerve fiber supplying the Golgi tendon organ belongs to **Ib type.** The nerve fiber supplying Golgi tendon organ ramifies into many branches. Each branch ends in the form of a knob.

FUNCTIONS OF GOLGI TENDON ORGAN

Golgi tendon organ gives response to the change in the force or tension developed in the skeletal muscle during contraction. It is also the receptor for inverse stretch reflex and lengthening reaction and thereby prevents damage of muscle due to overstretching.

1. *Role of Golgi Tendon Organ in Forceful Contraction*

During powerful contraction, tension in the muscles increases and stimulates Golgi tendon organ, which discharges the sensory impulses. Impulses are transmitted by Ib sensory nerve fiber to an inhibitory interneuron in the spinal cord. Interneuron, in turn, causes development of **inhibitory postsynaptic potential** (IPSP) in motor neurons, which supply the muscle. Now, the contraction of the muscle is inhibited.

2. *Role of Golgi Tendon Organ in Inverse Stretch Reflex*

Inverse stretch reflex

Inverse stretch reflex is the sudden decrease in resistance due to relaxation (instead of contraction) when a

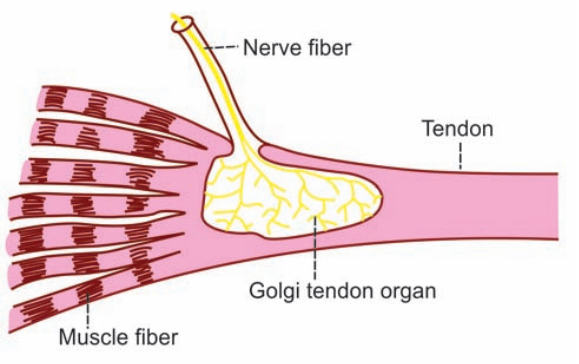

FIGURE 156.4: Golgi tendon apparatus

muscle is stretched excessively. It is also called **inverse myotatic reflex** and it is a **polysynaptic reflex.**

Inverse stretch reflex is actually the inhibition of contraction due to excessive stretching. So, it is also called the **autogenic inhibition.**

Mechanism of inverse stretch reflex

Excessive stretch of the muscle leads to activation of Golgi tendon organ, which send afferent impulses which cause:

i. Stimulation of inhibitory internuncial neuron, which in turn inhibits alpha motor neuron of the stretched muscle resulting in relaxation
ii. Stimulation of excitatory internuncial neuron, which in turn activates alpha motor neuron of the antagonistic muscle. It leads to contraction of antagonistic muscle and relaxation of stretched muscle.

3. Role of Golgi Tendon Organ in Lengthening Reaction

When tension increases during muscular contraction caused by stretch reflex, the Golgi tendon organ is activated. It causes development of a spinal reaction, which is called the lengthening reaction. It can be demonstrated in a decerebrate preparation.

In **decerebrate rigidity,** the extension of limbs is due to **spastic contraction** of extensor muscles. It is because of increased discharge from gamma motor neurons, which facilitates the **stretch reflex.**

In a decerebrate animal, some resistance is offered when the arm is flexed at elbow joint passively. That is, the arm cannot be flexed easily. This type of resistance is offered because of the stretch reflex developed in the triceps muscle. However, if forearm is flexed forcefully, resistance to flexion is abolished suddenly, leading to quick flexion of arm. It is called the lengthening reaction.

Lengthening reaction is due to the activation of Golgi tendon organ. The sudden flexion of arm is called the **Phillipson reflex** or **clasp knife reflex.**

■ PACINIAN CORPUSCLE

Pacinian corpuscle is a **mechanoreceptor** that senses pressure and vibration. It is situated in the deeper layers of skin. It is also situated in the tissues surrounding the joints such as fascia over the muscle, tendons and joint capsule. Pacinian corpuscles situated in these tissues are responsible for determining the position of joints.

Since pacinian corpuscle is a rapidly adapting receptor **(phasic receptor)** it is very sensitive to quick changes in the position of joints. So it is believed to send information about joint movement to CNS.

■ FREE NERVE ENDING

Free nerve ending is the receptor for pain sensation situated in skin, muscles, tendon, fascia and joints. As it is a slow adapting receptor **(tonic receptor)** it is maximally stimulated at specific joint positions. So it is believed to send information about joint position to CNS.

Posture and Equilibrium

Chapter 157

- DEFINITION
- BASIC PHENOMENA OF POSTURE
  - MUSCLE TONE
  - STRETCH REFLEX
- POSTURAL REFLEXES
  - CLASSIFICATION OF POSTURAL REFLEXES
  - STATIC REFLEXES
  - STATOKINETIC REFLEXES

DEFINITION

Subconscious **adjustment of tone** in different muscles in relation to every movement is known as the **posture.** Significance of posture is to make the movement smooth and accurate and to maintain the line of gravity constant or to keep the body in equilibrium with line of gravity. Posture is not an active movement. It is the **passive movement** associated with **redistribution of tone** in different groups of related muscles.

BASIC PHENOMENA OF POSTURE

Basic phenomena for maintenance of posture are muscle tone and stretch reflex.

MUSCLE TONE

Definition

Muscle tone is defined as the state of continuous and passive partial contraction of muscle with certain vigor and tension. It is also called **tonus.** It is also defined as resistance offered by the muscle to stretch.

Significance of Muscle Tone

Muscle tone plays an important role in maintenance of posture. Change in muscle tone enables movement of different parts of the body. Muscle tone is present in all the skeletal muscles. However, tone is more in antigravity muscles such as extensors of lower limb, trunk muscles and neck muscles.

Development of Muscle Tone

Gamma motor neurons and muscle spindle are responsible for the development and maintenance of muscle tone.

Muscle tone is purely a reflex process. This reflex is a **spinal segmental reflex.** It is developed by continual synchronous discharge of motor impulses from the gamma motor neurons present in the anterior gray horn of the spinal cord (Figs. 157.1 and 157.2).

Sequence of events

1. Impulses from the gamma motor neurons cause contraction of end portions of intrafusal fibers (stimulus)
2. This stretches and activates the central portion of the intrafusal fibers, which initiates the reflex action for development of muscle tone by discharging the impulses
3. Impulses from the central portion of intrafusal fibers pass through primary sensory nerve fibers (afferent fibers) and reach the anterior gray horn of spinal cord
4. These impulses stimulate the alpha motor neurons in anterior gray horn (center)

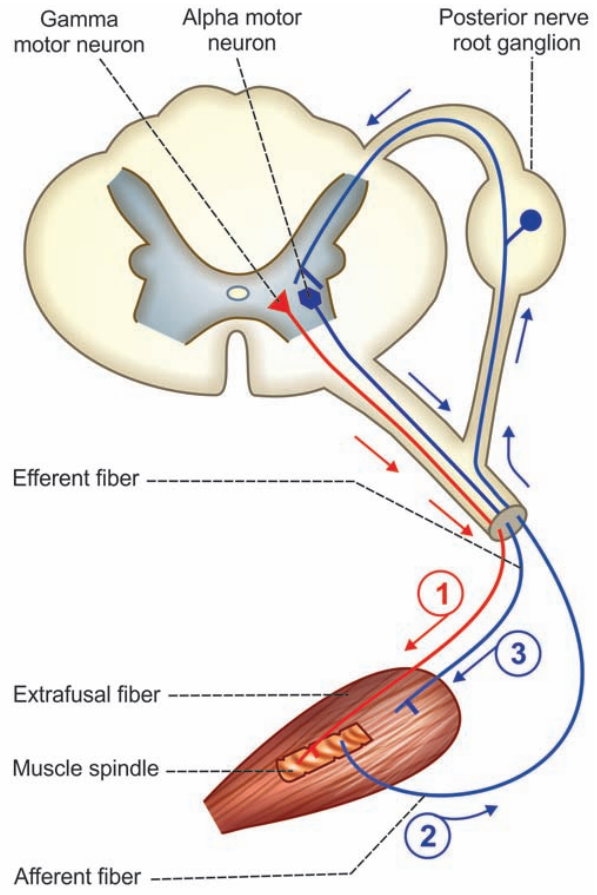

FIGURE 157.1: Development of muscle tone.1. Impulses from γ-motor neuron stimulate muscle spindle. 2. Afferent impulses from muscle spindle to α-motor neuron. 3. Efferent impulses from α-motor neuron produce contraction of extrafusal fibers and develop muscle tone.

5. Alpha motor neurons in turn, send impulses to extrafusal fibers of the muscle through spinal nerve fibers (efferent fibers)
6. These impulses produce partial contraction of the muscle fibers resulting in development of muscle tone (response).

When the frequency of discharge from gamma motor neurons increases, the activity of muscle spindle is increased and muscle tone also increases.

Stimulation of gamma motor neurons increases the muscle tone. Lesion in gamma motor neurons leads to loss of tone in muscles.

Regulation of Muscle Tone

Though the muscle tone is developed by discharges from gamma motor neurons, it is maintained continuously

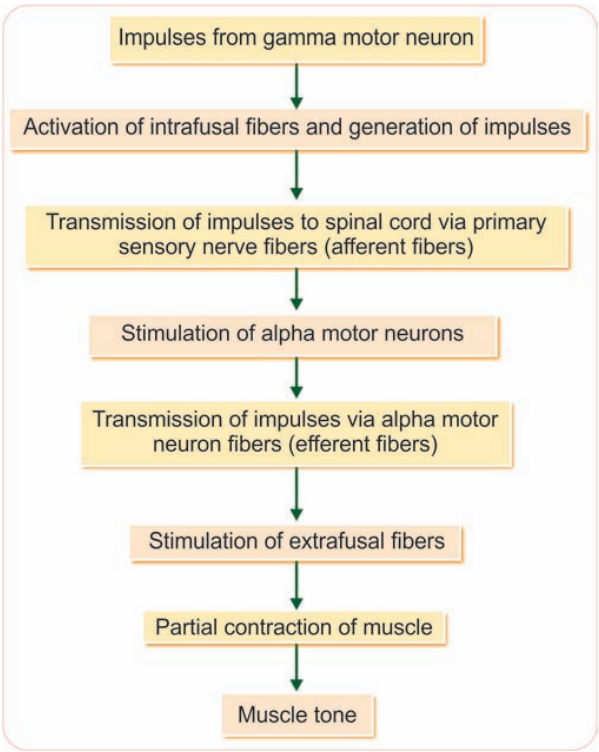
Impulses from gamma motor neuron
Activation of intrafusal fibers and generation of impulses
Transmission of impulses to spinal cord via primary sensory nerve fibers (afferent fibers)
Stimulation of alpha motor neurons
Transmission of impulses via alpha motor neuron fibers (efferent fibers)
Stimulation of extrafusal fibers
Partial contraction of muscle
Muscle tone

FIGURE 157.2: Schematic diagram showing development of muscle tone

and regulated by some supraspinal centers situated in different parts of brain. Some of these centers increase the muscle tone by sending **facilitatory impulses** while other centers decrease the muscle tone by **inhibitory impulses.**

Supraspinal facilitatory centers

Supraspinal centers, which increase the muscle tone:
1. Motor area 4 in cerebral cortex
2. Cerebellum
3. Descending facilitatory reticular system
4. Red nucleus
5. Vestibular nucleus.

Supraspinal inhibitory centers

Supraspinal centers, which decrease the muscle tone:
1. Suppressor areas of cerebral cortex
2. Basal ganglia
3. Descending inhibitory reticular system.

Role of motor area of cerebral cortex – coactivation

Motor area of cerebral cortex influences the activity of lower motor neurons by sending motor impulses through the pyramidal tract fibers. Motor impulses

from cerebral cortex stimulate both α-motor neurons and γ-motor neurons simultaneously. This type of simultaneous stimulation is called coactivation. It is also called **α-γ coactivation.** Stimulation of **α-motor** neurons causes contraction of **extrafusal fibers.** Stimulation of **γ-motor** neurons causes contraction of **intrafusal fibers,** which leads to increase in muscle tone.

Role of cerebellum and basal ganglia

It is interesting to find that cerebellum and basal ganglia influence the muscle tone without sending direct fibers to γ-motor neurons. These parts of brain influence the muscle tone indirectly through brainstem centers.

Role of brainstem centers

Brainstem centers which influence the γ-motor neurons are in reticular formation, red nucleus and vestibular nucleus. These centers modulate the discharge from γ-motor neurons by receiving signals from cerebral cortex, cerebellum and basal ganglia.

Abnormalities

Refer Chapter 34 for details of abnormalities of muscle tone.

■ STRETCH REFLEX

Basic reflex involved in maintenance of posture is the stretch reflex, which is described in detail in the previous chapter.

This reflex is normally present and serves particularly to maintain the body in an upright position. Such reflexes are, therefore more pronounced in extensor muscles.

■ POSTURAL REFLEXES

Postural reflexes are the reflexes which are responsible for maintenance of posture. Afferent impulses for the maintenance of posture arise from proprioceptors, vestibular apparatus and retina of eye and reach the centers in central nervous system (CNS). The centers, which maintain the posture, are located at different levels of CNS particularly cerebral cortex, cerebellum, brainstem and spinal cord. These centers send motor impulses to the different groups of skeletal muscles so that appropriate movements occur to maintain the posture.

■ CLASSIFICATION OF POSTURAL REFLEXES

Postural reflexes are generally classified into two groups:

A. Static reflexes
B. Statokinetic reflexes.

■ STATIC REFLEXES

Static reflexes are the postural reflexes that maintain posture at rest. Static reflexes are of four types:

I. General static reflexes or righting reflexes
II. Local static reflexes or supporting reflexes
III. Segmental static reflexes
IV. Statotonic or attitudinal reflexes.

I. *General Static Reflexes or Righting Reflexes*

General static reflexes are otherwise called righting reflexes because these reflexes help to maintain an upright position of the body. Righting reflexes help to govern the orientation of the head in space, position of the head in relation to the body and appropriate adjustment of the limbs and eyes in relation to the position of the head, so that upright position of the body is maintained.

When a cat, held with its back downwards, is allowed to fall through the air, it lands upon its paws, with the head and body assuming the normal attitude in a flash. A fish resists any attempt to turn it from its normal position and if it is placed in water upon its back, it flips almost instantly into the normal swimming position. All these actions occur because of the righting reflexes.

Righting reflexes consist of a chain of reactions, which occur one after another in an orderly sequence. Each reflex causes the development of the succeeding one.

Righting reflexes are divided into five types:

1. Labyrinthine righting reflexes acting on the neck muscles
2. Neck righting reflexes acting on the body
3. Body righting reflexes acting on the head
4. Body righting reflexes acting on the body
5. Optical righting reflexes.

First four reflexes are easily demonstrated on a thalamic animal or a normal animal, which is blindfolded.

1. *Labyrinthine righting reflexes acting on the neck muscles*

When a **thalamic animal** (rabbit) is suspended by holding at the pelvic region, its head turns up, until it assumes its normal position. It is because of reflexes arising from labyrinth, the sensory organ concerned with equilibrium of head, in regard to the position of the body. Turning the body of animal through air into different positions is followed by compensatory movements of the head. After extirpation of labyrinths, the head shows no compensatory movements when the rabbit is suspended. It hangs simply like that of a dead rabbit.

2. *Neck righting reflexes acting on the body*

It is noticed that during labyrinthine righting reflexes, the head raises up to normal position. It is because of the contraction of neck muscles. Now, the contraction of neck muscles produces proprioceptive impulses, which act on the body and rotate the body in relation to position of head. This reflex is well noticed, if the animal is laid down in resting position upon its side on a table.

3. *Body righting reflexes acting on the head*

Labyrinthine righting reflexes are not the only reflexes acting on neck muscles to cause rotation of head. If the animal is laid down upon its side on a table, the unequal distribution of pressure on that particular side of the body stimulates exteroceptors on the skin. Impulses thus generated by exteroceptors, act on neck muscles and rotate the head.

4. *Body righting reflexes acting on the body*

When the same animal is laid down on the table on its side, with head held down to table, to eliminate labyrinthine and neck righting reflexes, the body attempts to right itself by raising the lower parts. It is because of the impulses from exteroceptors on that side of body acting on the body itself.

5. *Optical righting reflexes*

Optical righting reflexes are initiated through the retinal impulses. Center for optical righting reflexes is in the occipital lobe of cerebral cortex. So, these reflexes are absent in thalamic animal. Optical righting reflexes help to correct the position of the body or head with the help of sight. It is proved in a labyrinthectomized animal. When such an animal is suspended, it rotates its head to normal position with the help of sight. But, the movements of head do not occur if eyes of the animal are closed.

Summary of righting reflexes

Following are the sequential events of righting reflexes:

i. When the animal is placed upon its back, labyrinthine reflexes acting upon neck muscles turn the head into its normal position in space, in relation to body
ii. Proprioceptive reflexes of neck muscles then bring the body into its normal position in relation to position of head
iii. When resting upon a rigid support, these reflexes are reinforced by the body righting reflexes on the head as well as on the body
iv. If the animal happens to be a **labyrinthectomized** one, then it makes an attempt to recover its upright position as a result of operation of the optical righting reaction. If the optical righting reflexes are abolished by covering the eyes, the righting ability is lost.

Optical righting reflexes are also demonstrated in 3 or 4 weeks old baby. When laid down on belly, i.e. prone position, the baby tries to raise the head to a vertical position.

Centers for righting reflexes

Centers for the first four righting reflexes are in **red nucleus** situated in midbrain. Center for optical righting reflexes is in the **occipital lobe** of cerebral cortex (Table 157.1).

II. *Local Static Reflexes or Supporting Reflexes*

Local static reflexes or supporting reactions support the body in different positions against gravity and also protect the limbs against hyperextension or hyperflexion.

Supporting reactions are classified into two types:

1. Positive supporting reflexes
2. Negative supporting reflexes.

1. *Positive supporting reflexes*

Positive supporting reflexes are the reactions, which help to fix the joints and make the limbs rigid like pillars, so that limbs can support the weight of the body against gravity. It is brought about by the simultaneous reflex contractions of both extensor and flexor muscles and other opposing muscles. The impulses for these reflexes arise from proprioceptors present in the muscles, joints and tendons and the exteroceptors, particularly pressure receptors present in deeper layers of the skin of sole. While standing, the positive supporting reflexes are developed in the following manner:

i. When an animal stands on its limbs, the pressure of the animal's paw upon the ground produces proprioceptive impulses from flexor and extensor muscles of the limbs, particularly in terminal segments of the limbs like digits, ankle or wrist. The proprioceptive impulses cause reflex contraction of the muscles of limbs making the limbs rigid.
ii. Excessive extension at the joints is checked or guarded by the **myotatic reflexes** setting up in the flexor muscles. When the flexor muscles are simultaneously contracting, extensor muscles cannot be stretched beyond the physiological limits. Similarly, over activity of the flexor muscles is prevented by the **stretch reflexes** developed in the extensor muscles.

TABLE 157.1: Static postural reflexes

Reflex		Center	Animal preparation to demonstrate
General static reflexes (Righting reflexes)	1. Labyrinthine righting reflexes acting on the neck muscles	Red nucleus situated in midbrain	Thalamic or normal blindfolded animal
	2. Neck righting reflexes acting on the body		
	3. Body righting reflexes acting on the head		
	4. Body righting reflexes acting on the body		
	5. Optical righting reflexes	Occipital lobe	Labyrinthectomized animal
Local static reflexes	1. Positive supporting reflexes	Spinal cord	Decorticate animal
	2. Negative supporting reflexes		
Segmental static reflexes	Crossed extensor reflex	Spinal cord	Spinal animals
Statotonic or attitudinal reflexes	1. Tonic labyrinthine and neck reflexes acting on the limbs	Medulla oblongata	Decerebrate animal
	2. Labyrinthine and neck reflexes acting on the eyes		

iii. Impulses arise even from exteroceptors while standing, when the sole remains in contact with the ground. It causes stimulation of the pressure receptors, which are present in deeper layers of the skin. These impulses from pressure receptors reinforce the rigidity of the limbs caused by the proprioceptive impulses.

2. *Negative supporting reflexes*

Relaxation of the muscles and unfixing of the joints enable the limbs to flex and move to a new position. It is called negative supporting reaction. It is brought about by raising the leg off the ground and plantar flexion of toes and ankle. When the leg is lifted off the ground, the exteroceptive impulses are stopped. When the toes and ankle joints are plantar flexed, the stretch stimulus for the plantar muscles is stopped. So, unlocking of the limbs occurs. Moreover, by the plantar flexion of the toes and ankle, the dorsiflexor muscles are stretched, causing relaxation of the extensors and contraction of the flexors of the knee.

The positive and negative supporting reactions are demonstrated well on a **decorticate animal.** The centers for the supporting reflexes are located in the spinal cord.

III. *Segmental Static Reflexes*

Segmental static reflexes are very essential for **walking.** During walking, in one leg, the flexors are active and the extensors are inhibited. On the opposite leg, the flexors are inhibited and extensors are active. Thus, the flexors and extensors of the same limb are not active simultaneously. It is known as **crossed extensor reflex.** It is due to the **reciprocal inhibition** and the neural mechanism responsible for this reflex is called **Sherrington reciprocal innervation.** Refer Chapter 142 for details.

Segmental static reflexes are demonstrated in **spinal animal.** And, the centers for these reflexes are situated in the spinal cord.

IV. *Statotonic or Attitudinal Reflexes*

Statotonic or attitudinal reflexes are developed according to the attitude of the body and are of two types:

1. Tonic labyrinthine and neck reflexes acting on the limbs
2. Labyrinthine and neck reflexes acting on the eyes.

1. *Tonic labyrinthine and neck reflexes acting on the limbs*

Tonic labyrinthine and neck reflexes decrease or increase the tone of the skeletal muscles of the limbs in accordance to the attitude or position of the head. These reflexes are best studied in decerebrate animal. The proprioceptors concerned with these reflexes are in the labyrinthine apparatus. Whenever the position of the head is altered, the receptors present in the labyrinth are stimulated and generate impulses. The impulses are also generated from the neck muscles when the position of the head is altered. The impulses

from labyrinth produce the same effect on all the four limbs. But the impulses from neck muscles cause opposite effects in the forelimbs and hind limbs.

The labyrinthine reflexes are particularly effective on extensor muscles. When the head is dorsiflexed, all the four limbs are extended maximally and when the head is ventriflexed, all the four limbs are flexed.

In a labyrinthectomized animal where only neck reflexes are operated, during dorsiflexion of the head, there is extension of the forelimbs and flexion of the hind limbs. The ventriflexion of the head causes flexion of the forelimbs and extension of the hind limbs.

The importance of these reflexes is understood well, while observing the movements during change in the attitude of a normal animal. When an animal turns to one side, the limbs of that side become rigid in order to support the weight of the body. A cat looking upwards, keeps the hind limbs flexed but forelimbs remain extended. It gives a suitable inclination to the back of the animal, which improves the positions of the head and eyes. When the cat looks down, forelimbs are flexed and hind limbs are extended, giving the proper supported inclination at the neck region.

2. *Labyrinthine and neck reflexes acting on the eyes*

According to the changes in the position of the head and neck, the eyes are also moved. These reflexes arise from labyrinth and neck muscles. Turning the head downward causes upward movement of the eyes. The eyes remain in this position as long as the position of the head is retained.

When the head is moved down, the tone in the superior recti and inferior oblique are increased and tone of inferior recti and superior oblique are reduced, so that the eyeballs move upwards. When the head is turned to one side, a corresponding compensatory movement of the eyes occurs.

When the head is turned to one side, the eyes deviate outward or inward in relation to the head. The eyes are moved in a direction opposite to that of the head movement. It is because of external and internal recti.

Centers for statotonic reflexes are present in the medulla oblongata.

■ STATOKINETIC REFLEXES

Statokinetic reflexes are the postural reflexes that maintain posture during movement. These reflexes are concerned with both angular **(rotatory)** and linear **(progressive)** movements. The vestibular apparatus is responsible for these reflexes. So, it is essential to study the structure and functions of vestibular apparatus to understand the statokinetic reflexes. The details of vestibular apparatus are described in Chapter 158.

Vestibular Apparatus

Chapter 158

- INTRODUCTION
- LABYRINTH
  - BONY LABYRINTH
  - MEMBRANOUS LABYRINTH
- FUNCTIONAL ANATOMY OF VESTIBULAR APPARATUS
  - SEMICIRCULAR CANALS
  - OTOLITH ORGAN OR VESTIBULE
- RECEPTOR ORGAN OF VESTIBULAR APPARATUS
  - CRISTA AMPULLARIS
  - MACULA
- NERVE SUPPLY TO VESTIBULAR APPARATUS
  - FIRST ORDER NEURON
  - SECOND ORDER NEURON
- FUNCTIONS OF VESTIBULAR APPARATUS
  - FUNCTIONS OF SEMICIRCULAR CANALS
  - FUNCTIONS OF OTOLITH ORGAN
- EFFECTS OF STIMULATION OF SEMICIRCULAR CANALS
  - ROTATIONAL MOVEMENT
  - CALORIC STIMULATION
- APPLIED PHYSIOLOGY – EFFECT OF LABYRINTHECTOMY
  - BILATERAL LABYRINTHECTOMY
  - UNILATERAL LABYRINTHECTOMY
- MOTION SICKNESS
  - DEFINITION
  - CAUSE
  - SYMPTOMS
  - PREVENTION

INTRODUCTION

Vestibular apparatus is the part of **labyrinth** or **inner ear.** It plays an important role in maintaining posture and equilibrium through **statokinetic reflexes.** Other part of labyrinth is the **cochlea,** which is concerned with sensation of hearing.

LABYRINTH

Labyrinth (inner ear) consists of two structures:

1. Bony labyrinth
2. Membranous labyrinth.

BONY LABYRINTH

Bony labyrinth is a series of cavities or channels present in the petrous part of temporal bone. Membranous labyrinth is situated inside bony labyrinth. The space between bony labyrinth and membranous labyrinth is filled with a fluid called **perilymph** or **periotic fluid.** This

fluid is similar to ECF in composition with large amount of sodium ions. Bony labyrinth encloses membranous labyrinth (Fig. 158.1).

■ MEMBRANOUS LABYRINTH

Membranous labyrinth is formed by membranous tubules and sacs. It consists of two portions:

1. Cochlea, which is concerned with sensation of hearing (Chapter 172)
2. Vestibular apparatus, which is concerned with posture and equilibrium.

Membranous labyrinth is filled with a fluid called **endolymph** or otic **fluid.** Endolymph is similar to ICF in composition. It has large quantity of potassium ions.

■ FUNCTIONAL ANATOMY OF VESTIBULAR APPARATUS

Vestibular apparatus is formed by three semicircular canals and otolith organ (vestibule).

■ SEMICIRCULAR CANALS

Semicircular canals are the tubular structures placed at right angles to each other. Because of this type of arrangement, semicircular canals represent the three axes of rotation, i.e. vertical, anteroposterior and transverse axes. Semicircular canals are named according to the situation as follows:

1. Anterior or superior canal
2. Posterior canal
3. Lateral or horizontal or external canal.

Anterior and posterior canals are situated vertically and the lateral canal is situated in horizontal plane (Fig. 158.2).

When the head is tilted forward at an angle of 30°, lateral canals of both the sides are at horizontal plane parallel to earth with the convexities directed outward and a little backward. Anterior canals are at vertical plane and directed forward and outward at 45°. Posterior canals are also at vertical plane, but directed backward and outward at 45°.

Therefore, the plane of position of anterior canal of one side is parallel to the plane of posterior canal of opposite side.

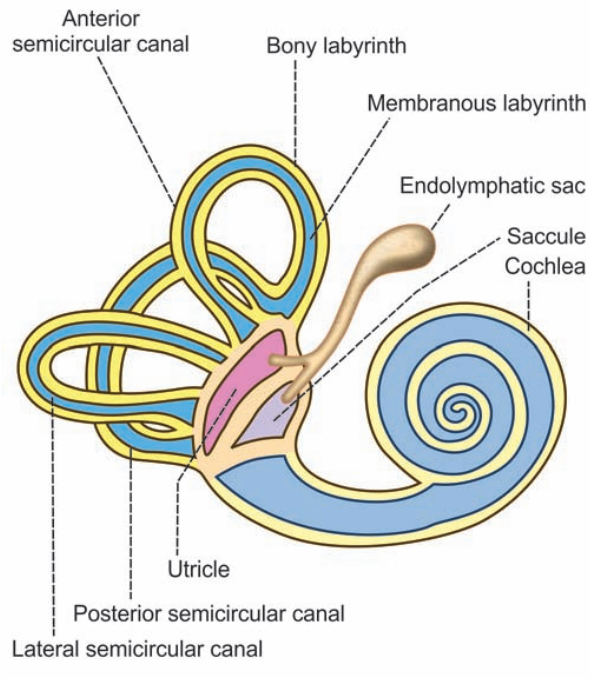

FIGURE 158.1: Labyrinth

Ampulla

There are two ends for each semicircular canal. One end is narrow and the other end is enlarged. The enlarged end is called ampulla. Ampulla contains the receptor organ of semicircular canals known as **crista ampullaris.** Ampulla of all the three canals and narrow end of horizontal canal open directly into the **utricle.** The narrow ends of anterior and posterior canals open into utricle jointly, by forming the **common crus.** Thus, all the three semicircular canals open into utricle by means of five openings. Utricle opens into **saccule.**

■ OTOLITH ORGAN OR VESTIBULE

Otolith organ or vestibule is formed by utricle and saccule. Often utricle and saccule are together called **otoliths.** Utricle communicates with saccule through **utriculosaccular duct.** Saccule communicates with cochlear duct through **ductus reuniens.** Another duct called endolymphatic duct arises from **utriculosaccular duct.** It ends in a bag-like structure called **endolymphatic sac,** which lies on the cranial surface of petrous bone.

■ RECEPTOR ORGAN IN VESTIBULAR APPARATUS

Receptor organ in semicircular canal is called **crista ampullaris** and that in otolith organ is called **macula.** These receptor organs contain the **proprioceptors.**

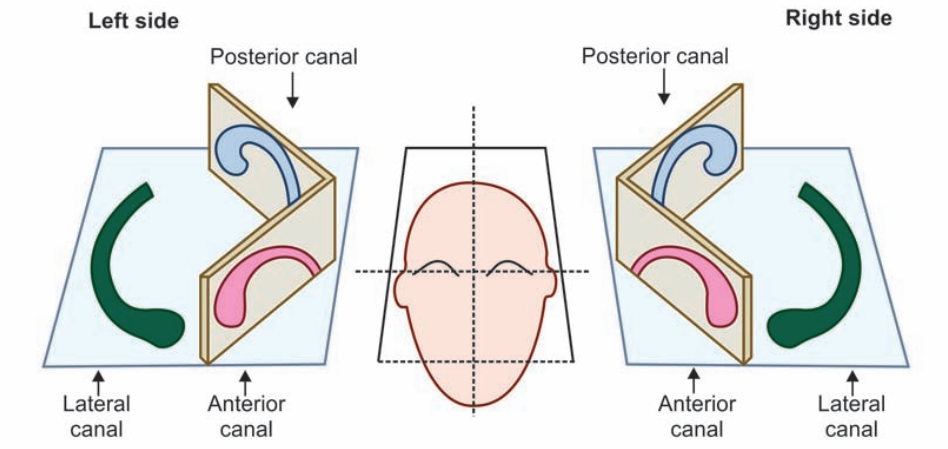

FIGURE 158.2: Position of semicircular canals when the head is tilted at 30°

■ RECEPTOR ORGAN IN SEMICIRCULAR CANAL – CRISTA AMPULLARIS

Crista ampullaris is a crest-like structure situated inside the ampulla of semicircular canals. The crest is formed by a **receptor epithelium (neuroepithelium),** which consists of hair cells, supporting cells and secreting epithelial cells. The secreting epithelial cells secrete the ground substance, **proteoglycan.** These cells are arranged in **planum semilunatum** (group of epithelial cells) around hair cells (Fig. 158.3).

Hair Cells

Hair cells are the receptor cells (proprioceptors) of crista ampullaris. There are two types of hair cells, type I and type II hair cells. Hair cells of semicircular canals, utricle and saccule receive both afferent and efferent nerve terminals.

Type I hair cells

Type I hair cells are flask shaped. Afferent nerve terminates in the form of a **calyx** that surrounds the cell body. Efferent nerve terminal ends on the surface of calyx.

Type II hair cells

These cells have a cylindrical or test tube shape. Both afferent and efferent nerve fibers terminate on the surface cell body without forming calyx.

Cilia of hair cells

Apex of each hair cell has a **cuticular plate.** From this plate, about 40 to 60 cilia arise, which are called **stereocilia.** Each stereocilium is attached at its tip to the neighboring taller one by means of a fine process called tip link. Because of the tip links, all the stereocilia are held together. One of the cilia is very tall, which is named as **kinocilium** (Fig. 158.4).

Cupula

From crista ampullaris, a dome-shaped gelatinous structure extends up to the roof of the ampulla. It is known as **cupula.** Cilia of hair cells are projected into cupula.

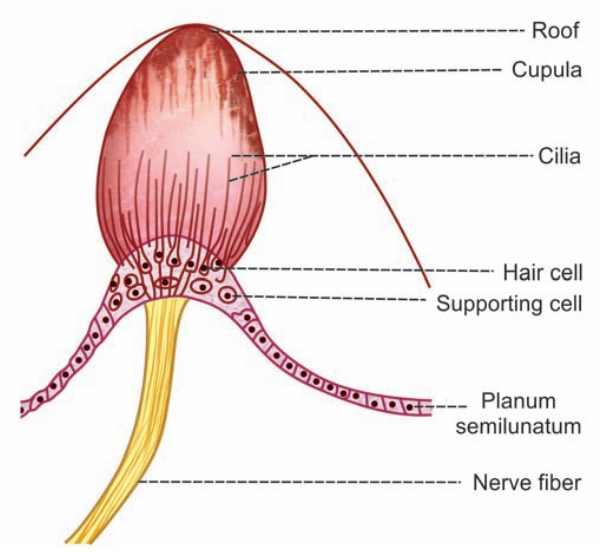

FIGURE 158.3: Crista ampullaris

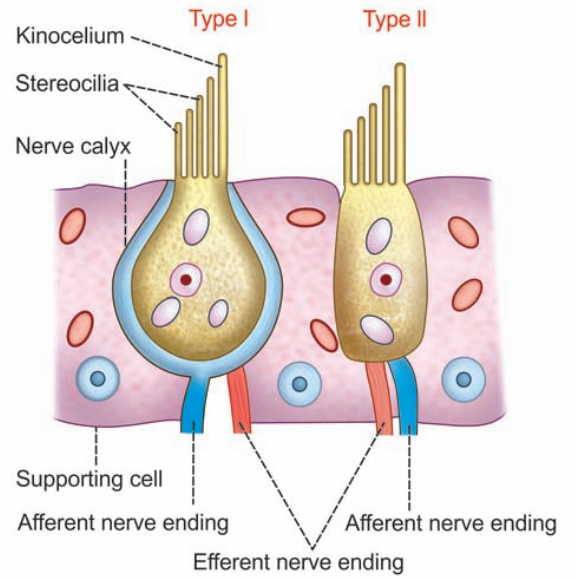

FIGURE 158.4: Hair cells of vestibular apparatus

■ RECEPTOR ORGAN IN OTOLITH ORGAN – MACULA

Receptor organ in otolith organ is called macula. Like crista ampullaris, macula is also formed by neuroepithelium and supporting cells. Neuroepithelium of macula also has two types of hair cells, the type I and type II hair cells (Fig. 158.5).

Otolith Membrane

Like crista ampullaris, macula is also covered by a gelatinous membrane called otolith membrane. It is a flat structure and not dome shaped like cupula. The **stereocilia** and **kinocelium** of each hair cell are embedded in otolith membrane. Otolith membrane contains some crystals, which are called **ear dust, otoconia** or **statoconia.** Otoconia are mainly constituted by calcium carbonate.

Situation of Macula

Situation of macula is different in utricle and saccule.

Macula in utricle

In utricle, the macula is situated in **horizontal plane,** so that the cilia from hair cells are in **vertical direction.**

Macula in saccule

In the case of saccule, macula is in **vertical plane** and the cilia are in **horizontal direction.**

■ NERVE SUPPLY TO VESTIBULAR APPARATUS

Impulses from the hair cells of crista ampullaris and maculae are transmitted to medulla oblongata and other parts of central nervous system (CNS) through the fibers of vestibular division of vestibulocochlear (VIII cranial) nerve.

■ FIRST ORDER NEURON

First order neurons of the sensory pathway are bipolar in nature. The soma of **bipolar cells** is present in vestibular or Scarpa ganglion, which is situated in the internal auditory meatus. Dendrites of bipolar cells reach the receptor organs, i.e. crista ampullaris and maculae in vestibular apparatus. Branches of the dendrites have close contact with basal part of **hair cells.** Dendrites terminating on type I hair cells are comparatively larger than those ending on type II hair cells.

Axons of the first order neurons (bipolar cells) form **vestibular division** of **vestibulocochlear nerve.** These fibers reach the medulla oblongata and terminate in vestibular nuclei. These nerve fibers are called primary vestibular fibers.

Vestibular Nuclei

There are four vestibular nuclei in the medulla oblongata, viz. superior, inferior, lateral and medial nuclei. Most of the primary vestibular fibers reaching superior and medial nuclei come from crista ampullaris of semicircular canals. Lateral vestibular nucleus receives fibers mainly from maculae of otolith organ and inferior vestibular nucleus receives fibers from both crista ampullaris and maculae.

Efferent nerve fibers to hair cells

Some neurons in vestibular nuclei send efferent fibers, which run back to the hair cells along with primary vestibular fibers (see above). It is believed that these efferent fibers to hair cells provide tonic inhibition of hair cells.

Fibers to Cerebellum

Fibers from some bipolar cells reach cerebellum directly and terminate in **flocculonodular lobe** or the **fastigial nucleus** in cerebellum.

■ SECOND ORDER NEURON

Second order neurons of this pathway are located in the four **vestibular nuclei.** Axons from vestibular nuclei

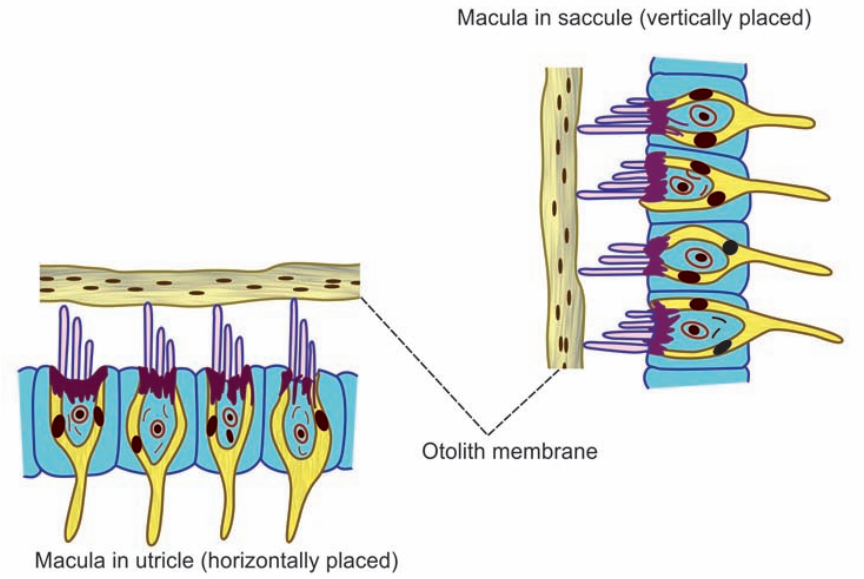

FIGURE 158.5: Macula in otolith organ

form the secondary vestibular fibers. Secondary vestibular fibers form four tracts:

1. Vestibulo-ocular tract
2. Vestibulospinal tract
3. Vestibuloreticular tract
4. Vestibulocerebellar tract.

1. *Vestibulo-ocular Tract*

Fibers from superior, medial and inferior vestibular nuclei descend downwards for short distance along with vestibulospinal tract. Afterwards, these fibers ascend through the medial longitudinal fasciculus and terminate in the nuclei of III, IV and VI cranial nerves, thus forming vestibulo-ocular tract. This tract is concerned with **movements of eyeballs** in relation to the position of the head.

2. *Vestibulospinal Tract*

Fibers from lateral nucleus descend downwards and form the vestibulospinal tract. Some fibers from this nucleus ascend upward and join medial longitudinal fasciculus. Fibers of vestibulospinal tract are involved in reflex **movements of head and body** during postural changes.

3. *Vestibuloreticular Tract*

Some fibers from vestibular nuclei reach the reticular formation of brainstem forming reticulospinal tract. These fibers are concerned with the **facilitation of muscle tone.**

4. *Vestibulocerebellar Tract*

Some fibers arising from all four vestibular nuclei form vestibulocerebellar tract and terminate in flocculonodular lobe and fastigial nuclei of cerebellum. This tract is involved in **coordination of movements** according to body position.

■ FUNCTIONS OF VESTIBULAR APPARATUS

Receptors of semicircular canals give response to **rotatory movements** or **angular acceleration** of the head. And receptors of utricle and saccule give response to linear acceleration of head.

Thus, the vestibular apparatus is responsible for detecting the position of head during different movements. It also causes reflex adjustments in the position of eyeball, head and body during postural changes.

■ FUNCTIONS OF SEMICIRCULAR CANALS

Semicircular canals are concerned with **angular** (rotatory) **acceleration.** Semicircular canals sense the rotational movement. Each semicircular canal is sensitive to rotation in a particular plane.

Superior Semicircular Canal

Superior semicircular canal gives response to rotation in **anteroposterior plane (transverse axis),** i.e. front to back movements like nodding the head while saying 'yes – yes'.

Horizontal Semicircular Canal

Horizontal semicircular canal gives response to rotation in **horizontal plane (vertical axis),** i.e. side to side movements (left to right or right to left) like shaking the head while saying 'no – no'.

Posterior Semicircular Canal

Posterior semicircular canal gives response to rotation in the **vertical plane (anteroposterior axis)** by which head is rotated from shoulder to shoulder.

Mechanism of Stimulation of Receptor Cells in Semicircular Canal

At the beginning of rotation, receptor cells are stimulated by movement of endolymph inside the semicircular canals. However, receptors are stimulated only at the beginning and at the stoppage of rotatory movements. And during rotation at a constant speed, these receptors are not stimulated.

When a person rotates in **clockwise direction** in horizontal plane (vertical axis), horizontal canal moves in clockwise direction. But there is no corresponding movement of **endolymph** inside the canal at the beginning of rotation. Because of the **inertia,** endolymph remains **static.** This phenomenon causes relative displacement of endolymph in the direction opposite to that of the rotation of head. That is, the fluid is pushed in anticlockwise direction.

Thus, in the right horizontal semicircular canal, the endolymph flows towards the ampulla and in the left canal, the fluid moves away from the ampulla (Fig. 158.6).

Movement of **endolymph** in semicircular canal, in turn causes corresponding movement of **gelatinous cupula.** Thus, in the right horizontal canal, the cupula moves towards the ampulla. Whereas in left canal cupula moves away from ampulla. In any semicircular canal, when cupula moves towards the ampulla, **stereocilia** of hair cells are pushed **towards kinocilium** leading to **stimulation of hair cells.** When cupula moves away from ampulla, the stereocilia are pushed away from kinocilium and hair cells are not stimulated.

Thus, at the commencement of rotation in clockwise direction around vertical axis, hair cells at ampulla of horizontal canal in right ear are stimulated. But, the hair cells in horizontal canal of left ear are not stimulated.

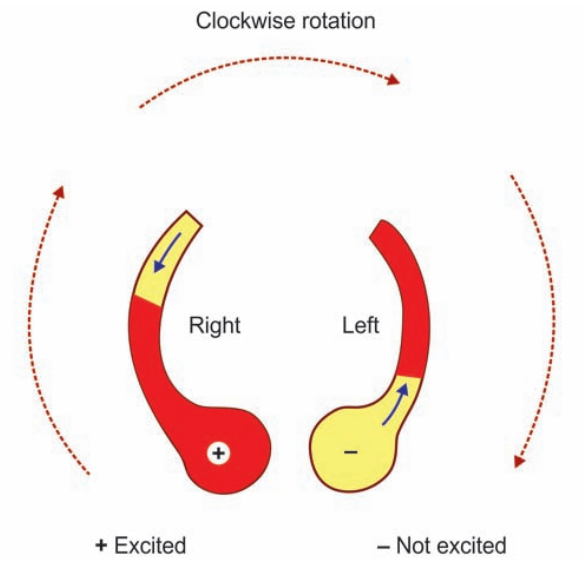

FIGURE 158.6: Movement of fluid and excitation of crista ampullaris in right horizontal semicircular canal during clockwise rotation.

Because of stimulation, the hair cells in right horizontal canal send information (impulses) through sensory nerve fibers to vestibular, cerebellar and reticular centers. Now, these centers send proper instructions to various muscles of the body to maintain equilibrium of the body during angular acceleration (rotation).

On the other hand, rotation in anticlockwise direction causes stimulation of hair cells in ampulla of horizontal canal in left ear only. Hair cells of horizontal canal in right ear are not stimulated. Stimulation of hair cells in left ear is followed by the process as in the case of clockwise rotation.

Electrical Potential in Hair Cells – Mechanotransduction

Mechanotransduction is a type of **sensory transduction** (Chapter 139) in the hair cell (receptor) by which the **mechanical energy** (movement of cilia in hair cell) caused by stimulus is converted into **action potentials** in the vestibular nerve fiber.

Resting membrane potential in hair cells is –60 mV. Movement of stereocilia of hair cells towards kinocilium causes opening of mechanically gated potassium channels (Chapter 3). It is followed by influx of potassium ions from endolymph which contains large amount of potassium ions. Potassium ions cause

development of **mild depolarization** in hair cells up to –50 mV. This type of depolarization is called **receptor potential.** Besides potassium ions, calcium ions also enter the hair cells from endolymph.

Receptor potential in hair cells is non-propagative. But, it causes **generation of action potential** in nerve fibers distributed to hair cells. Depolarization of hair cells causes them to release a neurotransmitter, which generates the action potential in the nerve fibers. It is believed that the probable neurotransmitter may be glutamate.

Movement of stereocilia in the opposite direction (away from kinocilium) causes **hyperpolarization** of hair cells. Calcium may play a role in the development of hyperpolarization. Hyperpolarization in hair cells stops generation of action potential in the nerve fibers (Fig. 158.7).

Adaptation of Receptors in Semicircular Canal during Rotation

Hair cells of crista ampullaris generate impulses even at rest. But, the frequency of discharge is very low at resting conditions. It is about 50 to 100 impulses per minute.

At the commencement of rotation, discharge of impulses reaches a higher frequency of 600 to 800 per minute, depending upon the speed of rotation. However, the rapid discharge of impulses lasts only for the first 20 to 25 seconds of rotation. Afterwards, even if rotation continues, the frequency of impulses falls back to the resting level. It is because of the adaptation of receptors during continuous rotation.

Cause for adaptation of receptor cells

At the onset of rotation, endolymph inside the semicircular canal does not move along with semicircular canal because of inertia of the fluid. So semicircular canal moves leaving the endolymph behind, which is like moving in the opposite direction. Now the endolymph is pushed into ampulla towards the utricle. It causes stimulation of hair cells but, after about 20 seconds due to the accumulation of endolymph, a pressure is developed in ampulla. Due to the back pressure, endolymph starts moving away from ampulla, i.e. it starts moving along with semicircular canal at the same speed. It causes adaptation of the hair cells.

Hair cells of crista ampullaris of vertical semicircular canals are stimulated during the rotation of head in anteroposterior or transverse axis. However, the mechanism involved is similar to that of the hair cells of crista ampullaris of horizontal canals.

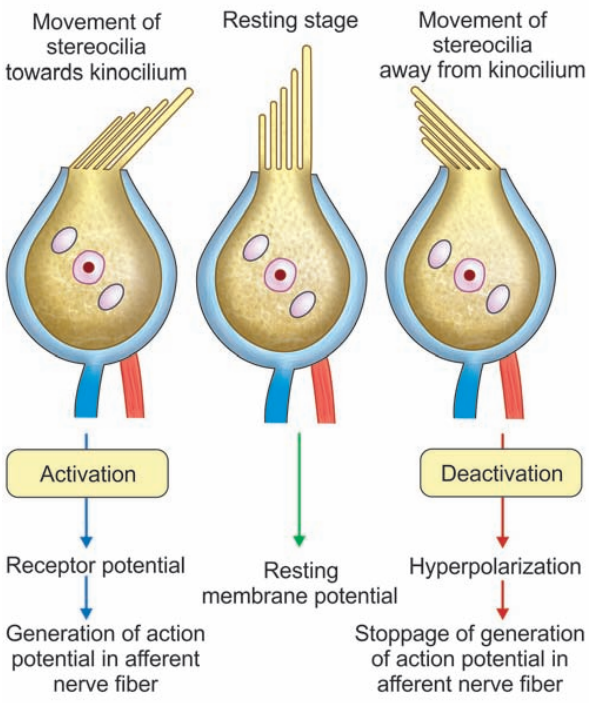

FIGURE 158.7: Mechanotransduction in hair cell of vestibular apparatus. During activation, receptor potential develops in hair cell due to the influx of potassium and calcium ions. Receptor potential causes release of neurotransmitter from hair cell, which induces development of action potential in the afferent nerve fiber.

Nystagmus

Nystagmus is the rhythmic oscillatory involuntary movements of eyeball. It is common during rotation. It is due to the natural stimulatory effect of vestibular apparatus during rotational acceleration. Nystagmus occurs both in physiological and pathological conditions.

Vestibulo-ocular reflex and nystagmus

Nystagmus is a **reflex phenomenon** that occurs in order to maintain the visual fixation. Since the movements of eyeballs occur in response to stimulation of vestibular apparatus this reflex is called **vestibulo-ocular reflex.**

Movement of eyeball during nystagmus

Nystagmus has two components of movement, which occur alternately:

1. Slow component
2. Quick component.

1. *Slow component*

At the beginning of rotation, since eyes are fixed at a particular object (point), eyeballs rotate slowly in the direction opposite to that of rotation of the head. It is called slow component of nystagmus. It is due to vestibulo-ocular reflex. This reflex is because of labyrinthine impulses reaching the ocular muscles via vestibular nuclei and III, IV and V cranial nerves.

2. *Quick component*

When the slow movement of eyeballs is limited, the eyeballs move to a new fixation point in the direction of rotation of head. This movement to a new fixation point occurs with a jerk. So, it is called the quick component. Quick component of nystagmus is due to the activation of some centers in brainstem.

Postrotatory nystagmus

Nystagmus that occurs immediately after stoppage of rotation is called postrotatory nystagmus. It is due to movement of cupula in opposite direction caused by the endolymph, when rotation is stopped. Postrotatory nystagmus can be demonstrated by Barany chair (see below for details).

Postrotatory Reactions

After the end of rotatory movement, two reactions occur:

1. Feeling of rotation in opposite direction
2. Postrotatory nystagmus.

1. *Feeling of rotation in the opposite direction*

When rotation in clockwise direction is stopped suddenly, endolymph moves in the direction of rotation in right horizontal semicircular canal although the semicircular canal stops moving. So, cupula moves away from utricle.

However, in the case of left horizontal semicircular canal, endolymph moves into ampulla. There, it pushes cupula towards the utricle and stimulates the hair cells in crista of left canal. It causes feeling of rotation in opposite direction when the rotation is stopped.

2. *Postrotatory nystagmus*

It is already explained above.

Nystagmus in Pathological Conditions

Nystagmus is very common in lesions of cerebellum and lesions of brainstem involving vestibular nuclei or vestibular nerve. It also occurs due to the damage of labyrinth.

■ FUNCTION OF OTOLITH ORGAN

Otolith organ is concerned with linear acceleration and detects acceleration in both horizontal and vertical planes. Utricle responds during horizontal acceleration and saccule responds during vertical acceleration.

Function of Utricle

Position of hair cells of macula helps utricle to respond to horizontal acceleration. In utricle, the macula is situated in horizontal plane with the hair cells in vertical plane (Fig. 158.5). While moving horizontally, because of inertia the otoconia move in opposite direction and pull the cilia of hair cells resulting in stimulation of hair cells.

For example, when the body moves forward, the otoconia fall back in otolith membrane and pull the cilia of hair cells backward. Pulling of cilia causes stimulation of hair cells. Hair cells send information (impulses) to vestibular, cerebellar and reticular centers. These centers in turn send instructions to various muscles to maintain equilibrium of the body during the forward movement.

Function of Saccule

Macula of saccule is situated in vertical plane with the cilia of hair cells in horizontal plane. While moving vertically, as in the case of utricle, otoconia of saccule move in opposite direction and pull the cilia resulting in stimulation of hair cells.

For example, while climbing up, the otoconia move down by pulling the cilia downwards. It stimulates the hair cells, which in turn send information to the brain centers. And the action follows as in the case of movement in horizontal plane.

Role of Otolith Organ in Resting Position

During resting conditions (in the absence of head movement), hair cells are stimulated continuously because of the pulling of **otoconia** by gravitational force. Stimulation of hair cells produces reflex movements of head and limbs for the maintenance of posture in relation to gravity. Because of this function, the receptors of otolith organ are called **gravity receptors.**

■ EFFECTS OF STIMULATION OF SEMICIRCULAR CANALS

Under experimental conditions, semicircular canals can be stimulated by two methods:

A. Rotational movement
B. Caloric stimulation.

ROTATIONAL MOVEMENT

Semicircular canal can be stimulated by rotational movement with the help of Barany chair.

Barany Chair

Barany chair is a revolving chair. The subject is seated on this chair with the head tilted forward at 30°. Both the eyes are closed. The chair is rotated at a speed of 30 RPM for about 20 seconds and then stopped.

Effects of Stimulation of Semicircular Canals by Rotation

Stimulation of semicircular canals during rotation in Barany chair produces some effects both during rotation and after the end of rotation.

Postrotatory Reactions

Twenty seconds after the stoppage of rotation in Barany chair, following reactions occur:

1. *Postrotatory nystagmus:* Eyes are closed during rotation by Barany chair. When eyes are opened after the sudden stoppage of rotation, nystagmus starts. Postrotatory nystagmus exists for about 30 seconds.
2. *Dizziness:* Immediately after stoppage of rotation, there is a feeling of unsteadiness. It is called the dizziness. Dizziness is associated with feeling of rotation in the opposite direction.
3. *Vertigo:* After the end of rotation, there is a feeling of environment whirling around or, there is a feeling of rotation of the person himself.
4. *Other effects:* Rotation for a longer period causes nausea and vomiting. Blood pressure falls by about 10 to 15 mm Hg. And, heart rate is reduced by 10 to 12 beats per minute.

Reaction during Rotation with Opened Eyes

If Barany chair is rotated with opened eyes, nystagmus occurs continuously throughout the period of rotation.

CALORIC STIMULATION

Semicircular canals can be stimulated bypassing hot or cold water into the ear by using a syringe. The transmission of change in temperature into labyrinth alters the specific gravity of endolymph. This in turn causes movement of cupula and stimulation of receptor cells.

Effects of Caloric Stimulation

Stimulation of semicircular canals by thermal stimulus develops nystagmus, vertigo and nausea. During the treatment for ear infection, temperature of fluid instilled into the ear must be equal to body temperature, so that, such symptoms of caloric stimulation are avoided.

APPLIED PHYSIOLOGY – EFFECT OF LABYRINTHECTOMY

BILATERAL LABYRINTHECTOMY

Removal of labyrinthine apparatus on both sides leads to complete loss of equilibrium.

Equilibrium could be maintained only by visual sensation. Postural reflexes are severely affected. There is loss of hearing sensation too.

UNILATERAL LABYRINTHECTOMY

Removal of labyrinthine apparatus on one side causes less effect on postural reflexes. However, severe autonomic symptoms occur. Autonomic symptoms are due to unbalanced generation of impulses from the unaffected labyrinthine apparatus.

Symptoms are nausea, vomiting and diarrhea. During movement, the symptoms become very severe.

The unaffected labyrinthine apparatus starts compensating the loss of functions of affected labyrinth. Hence, the symptoms disappear slowly after a few months.

MOTION SICKNESS

DEFINITION

Motion sickness is defined as the syndrome of physiological response during movement (travel) to which the person is not adapted. It can occur while traveling in any form of vehicle like automobile, ship, aircraft or spaceship. Motion sickness that occurs while traveling in a watercraft is called seasickness.

CAUSE

Motion sickness is due to excessive and repeated stimulation of vestibular apparatus. Excessive and repeated stimulation of vestibular apparatus occurs because of:

1. Rapid and repeated change in rate of motion while traveling
2. Rapid and repeated change in direction.

Psychological factors such as anxiety about the unfamiliar modes of travel may be added up to cause motion sickness.

■ SYMPTOMS

1. Nausea
2. Vomiting
3. Sweating
4. Diarrhea
5. Pallor (paleness)
6. Excess salivation
7. Discomfort
8. Headache
9. Disorientation.

■ PREVENTION

Responses of motion sickness can be prevented by avoiding greasy and bulky food before travel and by taking antiemetic drugs (drugs preventing nausea and vomiting). In experimental animals, motion sickness is abolished by bilateral removal of vestibular apparatus, sectioning of vestibular nerve or ablation of flocculonodular lobe.

Chapter 159

Electroencephalogram (EEG)

- INTRODUCTION
- SIGNIFICANCE OF EEG
- METHOD OF RECORDING EEG
- WAVES OF EEG
- EEG DURING SLEEP

INTRODUCTION

Electroencephalography is the study of electrical activities of brain. Electroencephalogram (EEG) is the graphical recording of electrical activities of brain. Electrical activity of the brain is complicated when compared to that of a single nerve fiber or neuron. It is due to the involvement of large number of neurons and synapses.

German psychiatrist **Hans Berger** was the first one to analyze the EEG waves systematically and hence the EEG waves are referred as **Berger waves.**

SIGNIFICANCE OF EEG

Electroencephalogram is useful in the diagnosis of neurological disorders and sleep disorders. EEG pattern is altered in the following neurological disorders:

1. **Epilepsy,** which occurs due to excessive discharge of impulses from cerebral cortex
2. **Disorders of midbrain** affecting ascending reticular activating system
3. **Subdural hematoma** during which there is collection of blood in subdural space over the cerebral cortex.

METHOD OF RECORDING EEG

Electroencephalograph is the instrument used to record EEG. The electrodes called **scalp electrodes** from the instrument are placed over unopened skull or over the brain after opening the skull or by piercing into brain. Electrodes are of two types, unipolar and bipolar electrodes. While using bipolar electrodes, both the terminals are placed in different parts of brain.

When unipolar electrodes are used, the active electrode is placed over cortex and the indifferent electrode is kept on some part of the body away from cortex.

WAVES OF EEG

Electrical activity recorded by EEG may have synchronized or desynchronized waves. **Synchronized waves** are the regular and invariant waves, whereas **desynchronized waves** are irregular and variant. In normal persons, EEG has three frequency bands (Fig. 159.1):

1. Alpha rhythm
2. Beta rhythm
3. Delta rhythm.

In addition to these three types of waves, EEG in children shows theta waves.

ALPHA RHYTHM

Alpha rhythm consists of rhythmical waves, which appear at a frequency of 8 to 12 waves/second with the amplitude of 50 μV. Alpha waves are **synchronized waves.**

Alpha rhythm is obtained in i**nattentive brain** or **mind** as in drowsiness, light sleep or narcosis with closed eyes. It is abolished by visual stimuli or any other type of stimuli or by mental effort. So, it is diminished when eyes are opened.

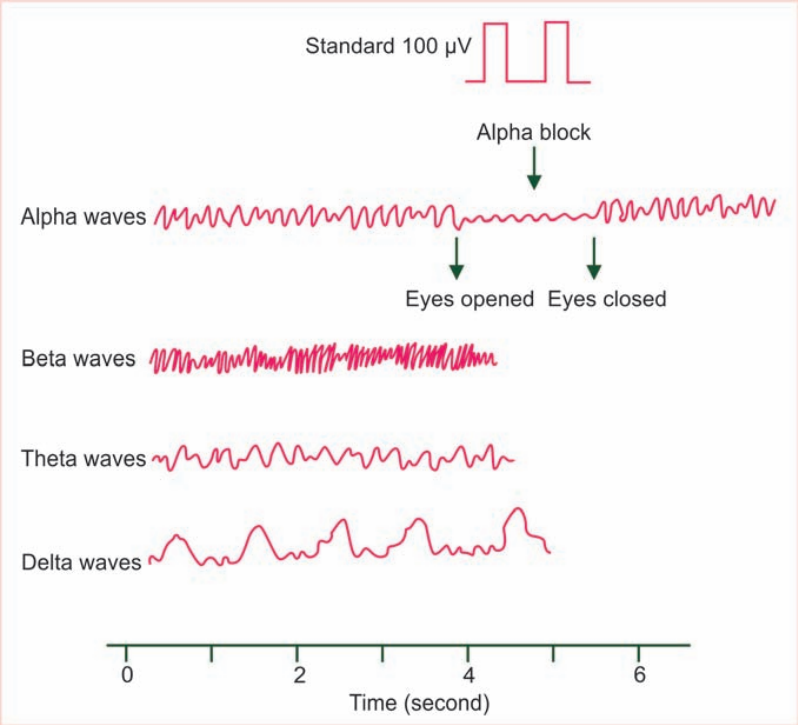

FIGURE 159.1: Waves of electroencephalogram

Waves of alpha rhythm are most marked in parieto-occipital area. Sometimes these waves appear in other areas also.

Alpha Block

Alpha block is the replacement of synchronized alpha waves in EEG by desynchronized and low voltage waves when the eyes are opened. The desynchronized waves do not have specific frequency. It occurs due to any form of sensory stimulation or mental concentration, such as solving arithmetic problems.

Desynchronization is the common term used for replacement of regular alpha waves with irregular low voltage waves. It is due to the loss of synchronized activity in neural elements that are responsible for regular wave pattern.

■ BETA RHYTHM

Beta rhythm includes high frequency waves of 15 to 60 per second but, the amplitude is low, i.e. 5 to 10 μV. Beta waves are **desynchronized waves.** Beta rhythm is recorded during mental activity or mental tension or arousal state. It is not affected by opening the eyes.

During higher mental activity or peak performance state like conscious activity, problem solving and fear, very high frequency waves of 30 to 100 per second appear. Some controversy exists in naming such waves. Often very high frequency waves are called **gamma rhythm.** However, many scientists consider these waves as beta rhythm.

■ DELTA RHYTHM

Delta rhythm includes waves with low frequency and high amplitude. These waves have the frequency of 1 to 5 per second with the amplitude of 20 to 200 μV. It is common in early childhood during waking hours. In adults, it appears mostly during **deep sleep.**

Presence of delta waves in adults during conditions other than sleep indicates the pathological process in brain like tumor, epilepsy, increased intracranial pressure and mental deficiency or depression. These waves are not affected by opening the eyes.

■ THETA WAVES

Theta waves are obtained generally in children below 5 years of age. These waves are of low frequency and low voltage waves. Frequency of theta waves is 4 to 8 per second and the amplitude is about 10 μV.

■ EEG DURING SLEEP

Changes in the EEG pattern during sleep are described in Chapter 160.

Physiology of Sleep

Chapter 160

- DEFINITION
- SLEEP REQUIREMENT
- PHYSIOLOGICAL CHANGES DURING SLEEP
- TYPES OF SLEEP
- STAGES OF SLEEP AND EEG PATTERN
- MECHANISM OF SLEEP
- APPLIED PHYSIOLOGY – SLEEP DISORDERS

DEFINITION

Sleep is the natural periodic **state of rest for mind and body** with closed eyes characterized by partial or complete loss of consciousness. Loss of consciousness leads to decreased response to external stimuli and decreased body movements. Depth of sleep is not constant throughout the sleeping period. It varies in different stages of sleep.

SLEEP REQUIREMENT

Sleep requirement is not constant. However, average sleep requirement per day at different age groups is:

1. Newborn infants : 18 to 20 hours
2. Growing children : 12 to 14 hours
3. Adults : 7 to 9 hours
4. Old persons : 5 to 7 hours.

PHYSIOLOGICAL CHANGES DURING SLEEP

During sleep, most of the body functions are reduced to basal level. Following are important changes in the body during sleep:

1. PLASMA VOLUME

Plasma volume decreases by about 10% during sleep.

2. CARDIOVASCULAR SYSTEM

Heart Rate

During sleep, the heart rate reduces. It varies between 45 and 60 beats per minute.

Blood Pressure

Systolic pressure falls to about 90 to 110 mm Hg. Lowest level is reached about 4th hour of sleep and remains at this level till a short time before waking up. Then, the pressure commences to rise. If sleep is disturbed by exciting dreams, the pressure is elevated above 130 mm Hg.

3. RESPIRATORY SYSTEM

Rate and force of respiration are decreased. Respiration becomes irregular and **Cheyne-Stokes type** of periodic breathing may develop.

4. GASTROINTESTINAL TRACT

Salivary secretion decreases during sleep. Gastric secretion is not altered or may be increased slightly. Contraction of empty stomach is more vigorous.

5. EXCRETORY SYSTEM

Formation of urine decreases and specific gravity of urine increases.

6. SWEAT SECRETION

Sweat secretion increases during sleep.

7. LACRIMAL SECRETION

Lacrimal secretion decreases during sleep.

8. MUSCLE TONE

Tone in all the muscles of body except ocular muscles decreases very much during sleep. It is called sleep paralysis.

9. REFLEXES

Certain reflexes particularly knee jerk, are abolished. **Babinski sign** becomes positive during deep sleep. Threshold for most of the reflexes increases. Pupils are constricted. Light reflex is retained. Eyeballs move up and down.

10. BRAIN

Brain is not inactive during sleep. There is a characteristic cycle of brain wave activity during sleep with irregular intervals of dreams. Electrical activity in the brain varies with stages of sleep (see below).

TYPES OF SLEEP

Sleep is of two types:

1. Rapid eye movement sleep or REM sleep
2. Non-rapid eye movement sleep, NREM sleep or non-REM sleep.

1. RAPID EYE MOVEMENT SLEEP – REM SLEEP

Rapid eye movement sleep is the type of sleep associated with rapid conjugate movements of the eyeballs, which occurs frequently. Though the eyeballs move, the sleep is deep. So, it is also called **paradoxical sleep.** It occupies about 20% to 30% of sleeping period. Functionally, REM sleep is very important because, it plays an important role in consolidation of memory. Dreams occur during this period.

2. NON-RAPID EYE MOVEMENT SLEEP – NREM OR NON-REM SLEEP

Non-rapid eye movement (NREM) sleep is the type of sleep without the movements of eyeballs. It is also called **slow-wave sleep.** Dreams do not occur in this type of sleep and it occupies about 70% to 80% of total sleeping period. Non-REM sleep is followed by REM sleep.

Differences between the two types of sleep are given in Table 160.1.

STAGES OF SLEEP AND EEG PATTERN

RAPID EYE MOVEMENT SLEEP

During REM sleep, electroencephalogram (EEG) shows irregular waves with high frequency and low amplitude. These waves are **desynchronized waves.**

NON-RAPID EYE MOVEMENT SLEEP

The NREM sleep is divided into four stages, based on the EEG pattern. During the stage of wakefulness, i.e. while lying down with closed eyes and relaxed mind, the **alpha waves** of EEG appear. When the person proceeds to drowsy state, the alpha waves diminish (Fig. 160.1).

Stage I: Stage of Drowsiness

Alpha waves are diminished and abolished. EEG shows only **low voltage fluctuations** and **infrequent delta waves.**

Stage II: Stage of Light Sleep

Stage II is characterized by **spindle bursts** at a frequency of 14 per second, superimposed by low voltage **delta waves.**

TABLE 160.1: Rapid eye movement (REM) sleep and non-rapid eye movement (NREM) sleep

Characteristics	REM sleep	Non-REM sleep
1. Rapid eye movement (REM)	Present	Absent
2. Dreams	Present	Absent
3. Muscle twitching	Present	Absent
4. Heart rate	Fluctuating	Stable
5. Blood pressure	Fluctuating	Stable
6. Respiration	Fluctuating	Stable
7. Body temperature	Fluctuating	Stable
8. Neurotransmitter	Noradrenaline	Serotonin

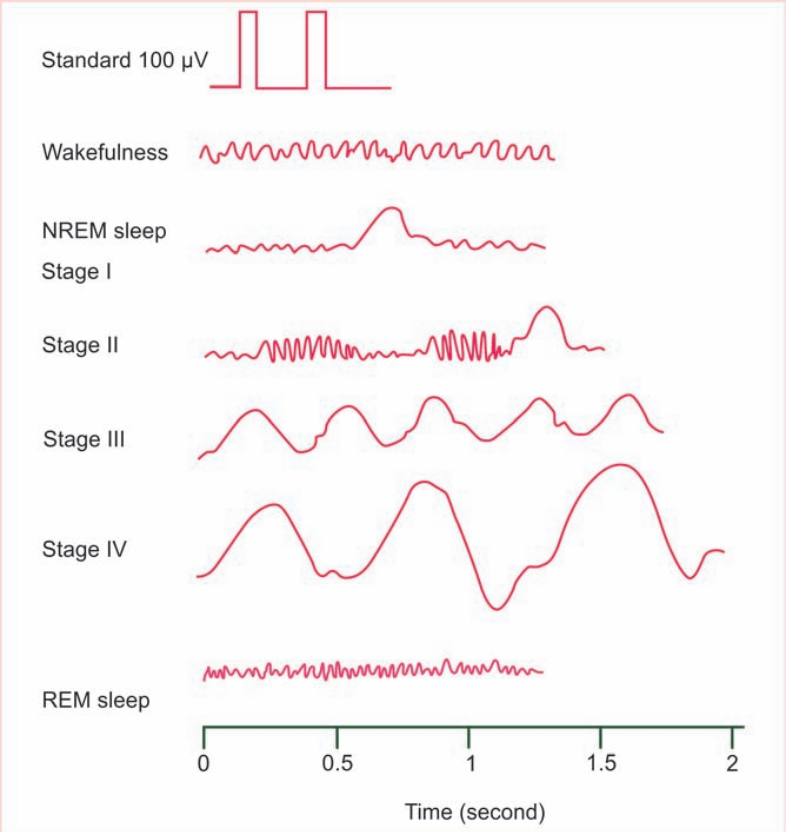

FIGURE 160.1: Electroencephalogram during wakefulness, different stages of NREM sleep and REM sleep. NREM = Non-rapid eye movement, REM = Rapid eye movement.

Stage III: Stage of Medium Sleep

During this stage, the spindle bursts disappear. Frequency of delta waves decreases to 1 or 2 per second and amplitude increases to about 100 μV.

State IV: Stage of Deep Sleep

Delta waves become more prominent with low frequency and high amplitude.

■ MECHANISM OF SLEEP

Sleep occurs due to the activity of some **sleep-inducing centers** in brain. Stimulation of these centers induces sleep. Damage of sleep centers results in sleeplessness or persistent wakefulness called **insomnia.**

■ SLEEP CENTERS

Complex pathways between the reticular formation of brainstem, diencephalon and cerebral cortex are involved in the onset and maintenance of sleep. However, two centers which induce sleep are located in brainstem:

1. Raphe nucleus
2. Locus ceruleus of pons.

Recently, many more areas that induce sleep are identified in the brain of animals. Inhibition of ascending reticular activating system also results in sleep.

1. *Role of Raphe Nucleus*

Raphe nucleus is situated in lower pons and medulla. Activation of this nucleus results in non-REM sleep. It is due to release of **serotonin** by the nerve fibers arising from this nucleus. Serotonin induces non-REM sleep.

2. *Role of Locus Ceruleus of Pons*

Activation of this center produces REM sleep. **Noradrenaline** released by the nerve fibers arising from locus ceruleus induces REM sleep.

Inhibition of Ascending Reticular Activating System

Ascending reticular activating system (ARAS) is responsible for wakefulness because of its afferent and efferent connections with cerebral cortex. Inhibition of ARAS induces sleep. Lesion of ARAS leads to permanent somnolence, i.e. coma.

APPLIED PHYSIOLOGY – SLEEP DISORDERS

1. INSOMNIA

Insomnia is the inability to sleep or abnormal wakefulness. It is the most common sleep disorder. It occurs due to systemic illness or mental conditions such as psychiatric problems, alcoholic addiction and drug addiction.

2. HYPERSOMNIA

Hypersomnia is the excess sleep or excess need to sleep. It occurs because of lesion in the floor of the third ventricle, brain tumors, encephalitis, chronic bronchitis and disease of muscles. Hypersomnia also occurs in endocrine disorders such as myxedema and diabetes insipidus.

3. NARCOLEPSY AND CATAPLEXY

Narcolepsy is the sudden attack of **uncontrollable sleep.** Cataplexy is sudden **outburst of emotion.** Both the diseases are due to hypothalamic disorders. Refer Chapter 149 for details.

4. SLEEP APNEA SYNDROME

Sleep apnea is the temporary stoppage of breathing repeatedly during sleep. Sleep apnea syndrome is the disorder that involves fluctuations in the rate and force of respiration during REM sleep with short apneic episode. Apnea is due to decreased stimulation of respiratory centers, arrest of diaphragmatic movements, airway obstruction (Chapter 127) or the combination of all these factors. When breathing stops, the resultant hypercapnia and hypoxia stimulate respiration.

Sleep apnea syndrome occurs in **obesity,** myxedema, enlargement of tonsil and lesion in brainstem. Common features of this syndrome are **loud snoring** (Chapter 127), restless movements, nocturnal insomnia, daytime sleepiness, morning headache and fatigue. In severe conditions, hypertension, right heart failure and stroke occur.

5. NIGHTMARE

Nightmare is a condition during sleep that is characterized by a sense of extreme uneasiness or discomfort or by frightful dreams. Discomfort is felt as of some heavy weight on the stomach or chest or as uncontrolled movement of the body. After a period of extreme anxiety, the subject wakes with a troubled state of mind. It occurs mostly during REM sleep. **Nightmare** occurs due to improper food intake, digestive disorders or nervous disorders. It also occurs during drug withdrawal or alcohol withdrawal.

6. NIGHT TERROR

Night terror is a disorder similar to nightmare. It is common in children. It is also called **pavor nocturnus** or **sleep terror.** The child awakes screaming in a state of fright and semiconsciousness. The child cannot recollect the attack in the morning. Nightmare occurs shortly after falling asleep and during non-REM sleep. There is no psychological disturbance.

7. SOMNAMBULISM

Somnambulism is getting up from bed and walking in the state of sleep. It is also called **walking during sleep** or **sleep walking** (somnus = sleep; ambulare = to walk). It varies from just sitting up in the bed to walking around with eyes open and performing some major complex task. The episode lasts for few minutes to half an hour. It occurs during non-REM sleep. In children, it is associated with bedwetting or night terror without any psychological disturbance. However, in adults it is associated with psychoneurosis.

8. NOCTURNAL ENURESIS

Nocturnal enuresis is the involuntary voiding of urine at bed. It is also called or **bedwetting.** It is common in children. Refer Chapter 57 for details.

9. MOVEMENT DISORDERS DURING SLEEP

Movement disorders occur immediately after falling asleep. **Sleep start** or **hypnic jerk** is the common movement disorder during sleep. It is characterized by sudden jerks of arms or legs. Sleep start is a physiological form of clonus.

Other movement disorders are teeth grinding (bruxism), banging the head and restless moment of arms or legs.

Epilepsy

Chapter 161

- INTRODUCTION
- TYPES OF EPILEPSY
- GENERALIZED EPILEPSY
  - GRAND MAL
  - PETIT MAL
  - PSYCHOMOTOR EPILEPSY
- LOCALIZED EPILEPSY

INTRODUCTION

Epilepsy

Epilepsy is a brain disorder characterized by convulsive seizures or loss of consciousness or both.

Convulsion and Convulsive Seizure

Convulsion refers to uncontrolled involuntary muscular contractions. Convulsive seizure means sudden attack of uncontrolled involuntary muscular contractions. It occurs due to **paroxysmal** (sudden and usually recurring periodically) **uncontrolled discharge** of impulses from neurons of brain, particularly cerebral cortex.

Epileptic

Patient affected by epilepsy is called epileptic. The person with epilepsy remains normal in between seizures. Epileptic attack develops only when excitability of the neuron is increased, causing excessive neuronal discharge.

TYPES OF EPILEPSY

Epilepsy is divided into two categories:

1. Generalized epilepsy
2. Localized epilepsy.

GENERALIZED EPILEPSY

Generalized epilepsy is the type of epilepsy that occurs due to excessive discharge of impulses from all parts of the brain. It is also called general onset seizure or general onset epilepsy.

Generalized epilepsy is subdivided into three types:

1. Grand mal
2. Petit mal
3. Psychomotor epilepsy.

GRAND MAL

Grand mal is characterized by sudden loss of consciousness, followed by convulsion. Just before the onset of convulsions, the person feels the warning sensation in the form of some **hallucination.** It is called **epileptic aura.**

Convulsions occur in two stages:

a. Tonic stage
b. Clonic stage.

Tonic Stage

Initially, seizure is characterized by **tonic contractions** of muscle leading to **spasm.** Spasm causes twisting facial features, flexion of arm and extension of lower limbs.

Clonic Stage

Clonic convulsions develop after the tonic stage. This stage is characterized by violent jerky movements of limbs and face due to alternate severe contraction and relaxation of muscles.

At the end of attack, alternative tonic and clonic convulsions are seen. During the entire period of seizure, tongue may be bitten.

Electroencephalogram (EEG) shows fast waves with a frequency of 15 to 30 per second during tonic stage. Slow and large waves appear during clonic phase. After the attack, slow waves are recorded for some time. In between seizures, EEG shows delta waves in all types of epileptics.

Causes of Grand Mal

Cause of grand mal epilepsy is the excess neural activity in all parts of brain. Cause for stoppage of attack is neuronal fatigue. Factors which accelerate the neural activity resulting in grand mal epilepsy are:

i. Strong emotional stimuli
ii. Hyperventilation and alkalosis
iii. Effects of some drugs
iv. Uncontrolled high fever
v. Loud noises or bright light
vi. Traumatic lesions in any part of brain.

■ PETIT MAL

In this type of epilepsy, the person becomes **unconscious** suddenly without any warning. The unconsciousness lasts for a very short period of 3 to 30 seconds. Convulsions do not occur. However, the muscles of face show twitch-like contractions and there is blinking of eyes. Afterwards, the person recovers automatically and becomes normal. Frequency of attack may be once in many months or many attacks may appear in rapid series. It usually occurs in late childhood and disappears completely at the age of 30 or above.

EEG recording shows slow and large waves during the attack. Each wave is followed by a sharp spike. This type of waves appear from recording over any part of the cerebral cortex indicating the involvement of whole brain. Delta waves appear in between the seizures.

Causes of Petit Mal

Cause of petit mal is not known. It occurs in conditions like head injury, stroke, brain tumor and brain infection.

■ PSYCHOMOTOR EPILEPSY

Psychomotor epilepsy is characterized by **emotional outbursts** such as abnormal rage, sudden anxiety, fear or discomfort. There is **amnesia** or a confused mental state for some period. Some persons have the tendency to attack others bodily or rub their own face vigorously. In most cases, the persons are not aware of their activities. Some persons are very well aware of the actions, but still the abnormal actions cannot be controlled.

EEG recordings show low frequency rectangular waves, ranging between 2 and 4 per second.

Causes of Psychomotor Epilepsy

Causes of psychomotor epilepsy are the abnormalities in temporal lobe and tumor in hypothalamus and other regions of limbic system like amygdala and hippocampus.

■ LOCALIZED EPILEPSY

Epilepsy that occurs because of excessive discharge of impulses from one part of brain is called localized epilepsy. It is otherwise known as **local** or **focal epilepsy** or **local seizure.** It involves only a localized area of cerebral cortex or the deeper parts of cerebellum, which are affected by tumor, abscess or vascular defects. The abnormality starts from a particular area and spreads to adjacent areas, developing slow-spreading muscular contractions. Contractions usually start in the mouth region and spread down towards the legs. This type of seizure is also known as **jacksonian epilepsy.**

Causes of Localized Epilepsy

Localized epilepsy is caused by brain tumor.

Higher Intellectual Functions

Chapter 162

- HIGHER INTELLECTUAL FUNCTIONS
- LEARNING
  - DEFINITION
  - CLASSIFICATION
- MEMORY
  - DEFINITION
  - ANATOMICAL BASIS
  - PHYSIOLOGICAL BASIS
  - CHEMICAL OR MOLECULAR BASIS
  - CONSOLIDATION
  - CLASSIFICATION
  - DRUGS FACILITATING MEMORY
  - APPLIED PHYSIOLOGY
- CONDITIONED REFLEXES
  - DEFINITION
  - CLASSIFICATION
  - CLASSICAL CONDITIONED REFLEXES
  - TYPES AND PROPERTIES OF CLASSICAL CONDITIONED REFLEXES
  - POSITIVE CONDITIONED REFLEXES
  - NEGATIVE CONDITIONED REFLEXES
  - INSTRUMENTAL OR OPERANT CONDITIONED REFLEXES
  - PHYSIOLOGICAL BASIS OF CONDITIONED REFLEXES
- SPEECH
  - DEFINITION
  - MECHANISM
  - DEVELOPMENT
  - NERVOUS CONTROL
  - APPLIED PHYSIOLOGY
  - APHASIA
  - DYSARTHRIA OR ANARTHRIA
  - DYSPHONIA
  - STAMMERING

HIGHER INTELLECTUAL FUNCTIONS

Higher intellectual functions are very essential to make up the human mind. These functions are also called **higher brain functions** or **higher cortical functions.** The extensive outer layer of gray matter in cerebral cortex is responsible for higher intellectual functions.

Conditioned reflex forms the basis of all higher intellectual functions.

LEARNING

DEFINITION

Learning is defined as the process by which new information is acquired. It alters the behavior of a person on the basis of past experience.

CLASSIFICATION OF LEARNING

Learning is classified into two types:
1. Non-associative learning
2. Associative learning.

1. *Non-associative Learning*

Non-associative learning involves response of a person to only one type of stimulus. It is based on two factors:
- i. Habituation
- ii. Sensitization.

i. Habituation

Habituation means getting used to something, to which a person is constantly exposed. When a person is exposed to a stimulus repeatedly, he starts ignoring the stimulus slowly. During first experience, the event (stimulus) is novel and evokes a response. However, it evokes less response when it is repeated. Finally, the person is habituated to the event (stimulus) and ignores it.

ii. *Sensitization*

Sensitization is a process by which the body is made to become more sensitive to a stimulus. It is called **amplification of response.** When a stimulus is applied repeatedly, habituation occurs. But, if the same stimulus is combined with another type of stimulus, which may be pleasant or unpleasant, the person becomes more sensitive to original stimulus.

For example, a woman is sensitized to crying sound of her baby. She gets habituated to different sounds around her and sleep is not disturbed by these sounds. However, she suddenly wakes up when her baby cries because of sensitization to crying sound of the baby.

Thus, sensitization increases the response to an innocuous stimulus when that stimulus is applied after another type of stimulus.

2. *Associative Learning*

Associative learning is a complex process. It involves learning about relations between two or more stimuli at a time. Classic example of associative learning is the conditioned reflex, which is described later in this chapter.

MEMORY

DEFINITION

Memory is defined as the ability to recall past experience or information. It is also defined as retention of learned materials. There are various degrees of memory. Some memories remain only for few seconds, while others last for hours, days, months or even years together.

ANATOMICAL BASIS OF MEMORY

Anatomical basis of memory is the **synapse** in brain. Synapse for memory coding is slightly different from other synapses. Two separate presynaptic terminals are present here. One of the terminals is **primary presynaptic terminal,** which ends on postsynaptic neuron as in conventional synapse. This terminal is called sensory terminal, because sensations are transmitted to the postsynaptic neuron through this terminal (Fig. 162.1).

Other presynaptic terminal ends on the sensory terminal itself. This terminal is called **facilitator terminal.**

When, sensory terminal is stimulated alone without facilitator terminal, the firing from sensory terminal leads to habituation, i.e. the firing decreases slowly. On the other hand, if both the terminals are stimulated, facilitation occurs and the signals remain strong for long period, i.e. for few months to few years.

PHYSIOLOGICAL BASIS OF MEMORY

Memory is stored in brain by the alteration of synaptic transmission between the neurons involved in memory.

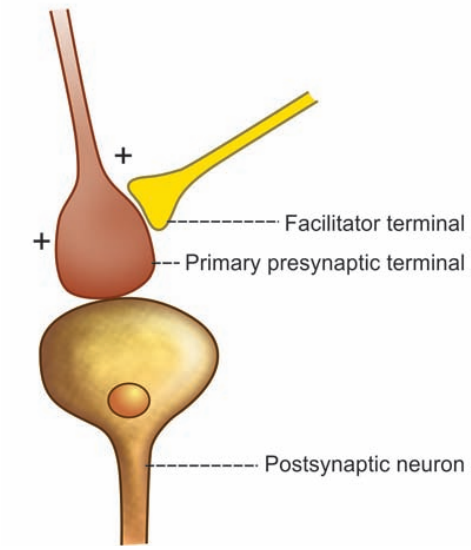

FIGURE 162.1: Synaptic terminal for memory encoding

Storage of memory may be facilitated or habituated depending upon many factors, such as neurotransmitter, synaptic transmission, functional status of brain, etc.

Facilitation

Facilitation is the process by which memory storage is enhanced. It involves increase in synaptic transmission and increased postsynaptic activity. Often, facilitation is referred as positive memory.

The process involved in facilitation of memory is called **memory sensitization.**

Habituation

Habituation is the process by which memory storage is **attenuated** (attenuation = decrease in strength, effect or value). It involves reduction in synaptic transmission and slow stoppage of postsynaptic activity. Sometimes, habituation is referred as **negative memory.**

Basis for Short-term Memory

Basic mechanism of memory is the development of new neuronal circuits by the formation of new synapses and facilitation of synaptic transmission. Number of presynaptic terminals and size of the terminals are also increased. This forms the basis of short-term memory.

Basis for Long-term Memory

When neuronal circuit is reinforced by constant activity, memory is consolidated and encoded into different areas of the brain. This encoding makes memory a permanent or a long-term memory.

Sites of Encoding

Hippocampus and Papez circuit (closed circuit between hippocampus, thalamus, hypothalamus and corpus striatum) are the main sites of memory encoding (Chapter 153). Frontal and parietal areas are also involved in memory storage.

Experimental Studies of Memory – Aplysia

Most of the experimental studies of memory and learning are based on the research carried out in the sea hare (sea snail) called *Aplysia*. This animal is useful in brain research because it has a simple uncomplicated nervous system that can be easily approached in living animal with simple dissection. Another advantage of this snail is that the individual nerve cells are large and brightly colored.

Nobel laureate, **Eric Kandel** was the pioneer to use *Aplysia* for the studies of memory and learning.

■ CHEMICAL OR MOLECULAR BASIS OF MEMORY

Memory Engram

Molecular basis of memory can be explained by memory engram. Memory engram is a process by which memory is facilitated and stored in the brain by means of structural and biochemical changes. Often, it is also called **memory trace.**

Molecular Basis of Facilitation

Molecular mechanism of facilitation is given in Figure 162.2. In this process, the neurotransmitter **serotonin** plays major role. Calcium ions increase the release of serotonin, which facilitates the synaptic transmission to a great extent, leading to memory storage.

Molecular Basis of Habituation

Habituation is due to passive closure of calcium channels of terminal membrane. Hence, the release of transmitter decreases, resulting in decrease in number of action potential in the postsynaptic neuron. So, the signals become weak and weakening of signals leads to habituation.

■ CONSOLIDATION OF MEMORY

The process by which a short-term memory is crystallized into a long-term memory is called memory consolidation. Consolidation causes permanent facilitation of synapses. It is possible by rehearsal mechanism, i.e. rehearsal of same information again and again accelerates and potentiates the degree of transfer of short-term memory into long-term memory. This is what happens in memorizing a poem or a phrase.

■ CLASSIFICATION OF MEMORY

Memory is classified by different methods, on the basis of various factors.

Short-term Memories and Long-term Memories

Generally, memory is classified as short-term memory and long-term memory.

1. *Short-term memory*

Short-term memory is the recalling events that happened very recently, i.e. within hours or days. It is also known as recent memory. For example, telephone number that is known today may be remembered till tomorrow. But if it is not recalled repeatedly, it may be forgotten on the third day.

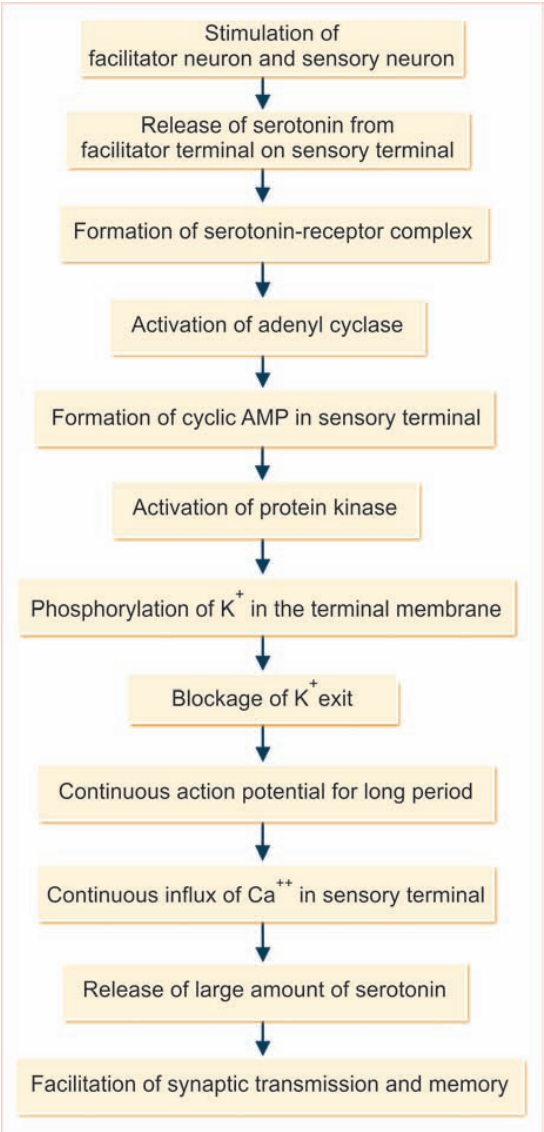
Stimulation of facilitator neuron and sensory neuron
Release of serotonin from facilitator terminal on sensory terminal
Formation of serotonin-receptor complex
Activation of adenyl cyclase
Formation of cyclic AMP in sensory terminal
Activation of protein kinase
Phosphorylation of K^+ in the terminal membrane
Blockage of K^+ exit
Continuous action potential for long period
Continuous influx of Ca^{++} in sensory terminal
Release of large amount of serotonin
Facilitation of synaptic transmission and memory

FIGURE 162.2: Memory engram

Short-term memory may be interrupted by many factors such as stress, trauma, drug abuse, etc.

There is another form of short-term memory called **working memory.** It is concerned with recollection of past experience for a very short period, on the basis of which an action is executed.

2. *Long-term memory*

Long-term memory is the recalling of events of weeks, months, years or sometimes lifetime. It is otherwise called the **remote memory.** Examples are, recalling first day of schooling, birthday celebration of previous year, picnic enjoyed last week, etc. Long-term memory is more resistant and is not disrupted easily.

Explicit and Implicit Memories

Physiologically, memory is classified into two types, namely explicit memory and implicit memory.

1. *Explicit memory*

Explicit memory is defined as the memory that involves conscious recollection of past experience. It consists of memories regarding events, which occurred in the external world around us. The information stored may be about a particular event that happened at a particular time and place. Explicit memory is otherwise known as **declarative memory** or **recognition memory.**

Examples of explicit memory are recollection of a birthday party celebrated three days ago, events taken place while taking breakfast, etc.

Explicit memory involves hippocampus and medial part of temporal lobe.

2. *Implicit memory*

Implicit memory is defined as the memory in which past experience is utilized without conscious awareness. It helps to perform various skilled activities properly. Implicit memory is otherwise known as **non-declarative memory** or **skilled memory.**

Examples of implicit memory are cycling, driving, playing tennis, dancing, typing, etc.

Implicit memory involves the sensory and motor pathways.

Memories Depending upon Duration

Depending upon duration, memory is classified into three types:

1. Sensory memory
2. Primary memory
3. Secondary memory.

1. *Sensory memory*

Sensory memory is the ability to retain sensory signals in sensory areas of brain, for a very short period of few seconds after the actual sensory experience, i.e. few hundred milliseconds. But, the signals are replaced by new sensory signals in less than 1 second. It is the initial stage of memory. It resembles working memory.

2. *Primary memory*

Primary memory is the memory of facts, words, numbers, letters or other information retained for few minutes at a time. For example, after searching and finding a

telephone number in the directory, we remember the number for a short while. After appreciating beautiful scenery, the details of it could be recalled for some time. Afterwards, it disappears from the memory.

Characteristic feature of this type of memory is that the information is available for recall easily from memory store itself. One need not search or squeeze through the mind, but this memory is easily replaced by new bits of memory, i.e. by looking into another telephone number, the first one may disappear.

3. *Secondary memory*

Secondary memory is the storage of information in brain for a longer period. The information could be recalled after hours, days, months or years. It is also called **fixed memory** or **permanent memory.** It resembles long-term memory.

■ DRUGS FACILITATING MEMORY

Several stimulants for central nervous system are shown to improve learning and memory in animals. Common stimulants are caffeine, physostigmine, amphetamine, nicotine, strychnine and metrazol. All these substances mentioned above facilitate the consolidation of memory.

■ APPLIED PHYSIOLOGY – ABNORMALITIES OF MEMORY

1. *Amnesia*

Loss of memory is known as amnesia. Amnesia is classified into two types:

i. Anterograde amnesia: Failure to establish new long-term memories. It occurs because of lesion in hippocampus.
ii. Retrograde amnesia: Failure to recall past remote long-term memory. It occurs in temporal lobe syndrome.

2. *Dementia*

Dementia is the progressive deterioration of intellect, emotional control, social behavior and motivation associated with loss of memory. It is an age-related disorder. Usually, it occurs above the age of 65 years. When it occurs under the age of 65, it is called **presenile dementia.**

Causes

Dementia occurs due to many reasons. Most common cause of dementia is Alzheimer disease. In about 75% of cases, dementia is due to this disease (given below). Other common causes of dementia are hydrocephalus, Huntington chorea, Parkinson disease, viral encephalitis, HIV infection, hypothyroidism, hypoparathyroidism, Cushing syndrome, alcoholic intoxication, poisoning by high dose of barbiturate, carbon monoxide, heavy metals, etc.

Clinical features

Common features are loss of recent memory, lack of thinking and judgment and personality changes. As the disease progresses, psychiatric features begin to appear. Motor functions are also affected. Finally, the patient has to lead a vegetative life without any thinking power. The person is speechless and is unable to understand anything.

There is no effective treatment for this disorder. Physostigmine, which inhibits cholinesterase causes moderate improvement.

3. *Alzheimer Disease*

Alzheimer disease is a progressive neurodegenerative disease. It is due to degeneration, loss of function and death of neurons in many parts of brain, particularly cerebral hemispheres, hippocampus and pons. There is reduction in the synthesis of most of the neurotransmitters, especially acetylcholine. Synthesis of acetylcholine decreases due to lack of enzyme choline acetyltransferase. Norepinephrine synthesis decreases because of degeneration of locus ceruleus. Dementia is the common feature of this disease.

■ CONDITIONED REFLEXES

■ DEFINITION

Conditioned reflex is the acquired reflex that requires learning, memory and recall of previous experience. It is acquired after birth and it forms the basis of learning.

Conditioned reflex is different from unconditioned reflex (Table 162.1). Unconditioned reflex is the inborn reflex, which does not need previous experience.

TABLE 162.1: Conditioned reflex Vs unconditioned reflex

Conditioned reflex	Unconditioned reflex
Acquired after birth	Inborn reflex
Needs previous experience	Does not need previous experience
Involves learning and memory	Does not involve learning and memory
Elicited by conditioned stimulus	Elicited by unconditioned stimulus

CLASSIFICATION OF CONDITIONED REFLEXES

Conditioned reflexes are classified into two types:

A. Classical conditioned reflexes
B. Instrumental conditioned reflexes.

CLASSICAL CONDITIONED REFLEXES

Classical conditioned reflexes are those reflexes, which are established by a **conditioned stimulus,** followed by an **unconditioned stimulus.**

Method of Study – Pavlov's Bell-Dog Experiments

Various types of classical conditioned reflexes and their properties are demonstrated by the classical bell-dog experiments (salivary secretion experiments), done by **Ivan Pavlov** and his associates.

In dogs, the duct of parotid gland or submandibular gland was taken outside through cheek or chin respectively and the saliva was collected by some special apparatus. Apparatus consisted of a funnel, which is sealed over the opening of the duct. Salivary secretion was measured in drops by means of an electrical recorder.

TYPES AND PROPERTIES OF CLASSICAL CONDITIONED REFLEXES

Classical conditioned reflexes are classified into two groups according to the properties of reflexes, namely excitation or inhibition:

I. Positive or excitatory conditioned reflexes
II. Negative conditioned reflexes.

POSITIVE CONDITIONED REFLEXES (EXCITATION OF CONDITIONED REFLEXES)

Types of positive conditioned reflexes:

1. Primary conditioned reflex
2. Secondary conditioned reflex
3. Tertiary conditioned reflex.

1. *Primary Conditioned Reflex*

Primary conditioned reflex is the reflex developed with one unconditioned stimulus and one conditioned stimulus. This reflex is established in the following way. The animal is fed with food (unconditioned stimulus). Simultaneously a flash of light (conditioned stimulus) is also shown. Both the stimuli are repeated for some days. After the development of reflex, the flash of light (conditioned stimulus) alone causes salivary secretion without food (unconditioned stimulus).

2. *Secondary Conditioned Reflex*

Secondary conditioned reflex is the reflex developed with one unconditioned stimulus and two conditioned stimuli. After establishment of a conditioned reflex with one conditioned stimulus, another conditioned stimulus is applied along with the first one. For example, the animal is fed with food (unconditioned reflex) and simultaneously a flash of light **(first conditioned stimulus)** and a bell sound **(second conditioned stimulus)** are applied. After development of the reflex, bell sound (second conditioned stimulus) alone can cause salivary secretion (Fig. 162.3).

3. *Tertiary Conditioned Reflex*

In this reflex, a **third conditioned stimulus** is added and the reflex is established. But, the reflex with more than three conditioned stimuli is not possible. Many types of conditioned stimuli associated with sight and hearing were employed by Pavlov.

NEGATIVE CONDITIONED REFLEXES (INHIBITION OF CONDITIONED REFLEXES)

The established conditioned reflexes can be inhibited by some factors. The inhibition is of two types:

1. External or indirect inhibition
2. Internal or direct inhibition.

1. *External or Indirect Inhibition*

Established conditioned reflex is inhibited by some form of stimulus, which is quite different from the conditioned stimulus. It is not related to conditioned stimulus.

For example, some disturbing factors like sudden entrance of a stranger, sudden noise or a strong smell can abolish the conditioned reflex and inhibit salivary secretion. This extra stimulus evokes the animal's curiosity and distracts the attention. According to Pavlov, it evokes an investigatory reflex. If the extra (inhibitory) stimulus is repeated for some time, its inhibitory effect gets weakened or abolished.

2. *Internal or Direct Inhibition*

There are four ways in which the established conditioned reflex is abolished by direct or internal factors, which are related to the conditioned stimulus.

i. Extinction of conditioned reflex
ii. Conditioned inhibition
iii. Inhibition by delay or delayed conditioned reflex
iv. Differential inhibition.

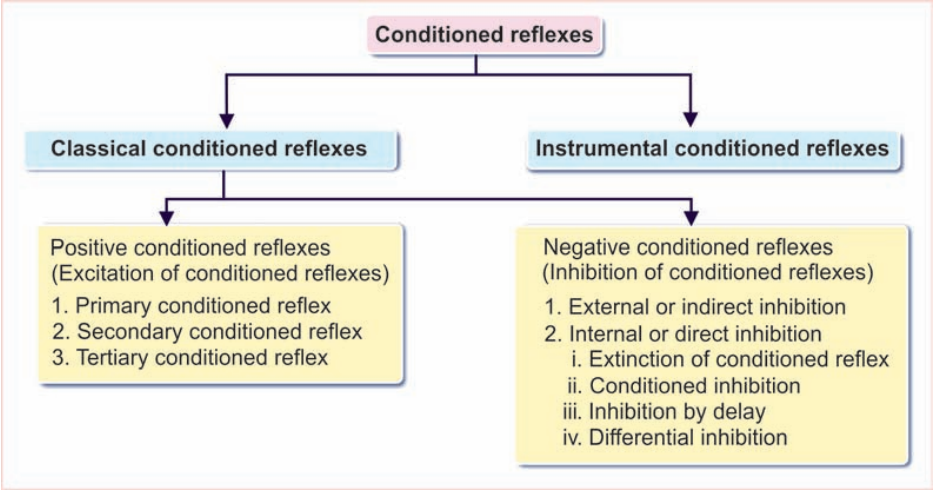

FIGURE 162.3: Conditioned reflexes

i. *Extinction of conditioned reflex*

Extinction is the failure of conditioned reflex. It occurs if an established conditioned reflex is not reinforced by unconditioned stimulus. After establishing a conditioned reflex, the conditioned stimulus must be coupled with unconditioned stimulus now and then, i.e. the conditioned stimulus must be reinforced by unconditioned stimulus. If a conditioned stimulus is given repeatedly several times, without reinforcing it by unconditioned stimulus, there is failure of conditioned reflex. However, the reflex is not abolished if the unconditioned reflex is also used in between.

ii. *Conditioned inhibition*

Conditioned inhibition is the failure of conditioned reflex due to introduction of an unknown (new) conditioned stimulus. When a conditioned stimulus like flash of light is effective, if another conditioned stimulus like a bell sound is applied along with this stimulus suddenly, the response does not occur. Of course, if these two conditioned stimuli are given with unconditioned stimulus (food) repeatedly, the secondary conditioned reflex is developed.

iii. *Inhibition by delay or delayed conditioned reflex*

Inhibition by delay is the absence of response or delayed response that occurs while eliciting a conditioned reflex by delaying the unconditioned stimulus. While establishing a conditioned reflex, the conditioned stimulus (light or sound) must be followed by unconditioned stimulus (food) immediately. If the unconditioned stimulus is applied after a long period, response may be absent or delayed. The reflex is called delayed conditioned reflex.

iv. *Differential inhibition*

Differential inhibition is the failure of conditioned reflex that occurs when the conditioned stimulus is altered. When an animal is trained or conditioned for a particular type of conditioned stimulus and if this stimulus is altered even slightly, the response does not occur. The animal is able to discriminate the difference. For example, the alteration in frequency of sound or intensity of light abolishes the conditioned reflex (Table 162.2).

■ INSTRUMENTAL OR OPERANT CONDITIONED REFLEXES

Instrumental conditioned reflexes are those reflexes in which the behavior of the person is instrumental. This type of reflexes is developed by the conditioned stimulus, followed by a reward or a punishment. The instrumental conditioned reflexes are also called **operant conditioned reflexes** or **Skinner conditioning.**

During the development of this type of reflexes, the animal is taught to perform some task, in order to obtain a reward or to avoid a punishment. Accordingly, the instrumental conditioned reflexes are of several types, such as:

1. Conditioned avoidance reflex
2. Food avoidance reflex
3. Conditioned reward reflex.

Conditioned Avoidance Reflex

Conditioned avoidance reflex is the reflex by which the animal is trained to avoid an electric shock, by pressing a bar.

TABLE 162.2: Causes for inhibition of conditioned reflex

Type of inhibition		Cause
External inhibition		Disturbing factors like a stranger, noise or strong smell
Internal inhibition	Extinction of conditioned reflex	Failure to reinforce the conditioned reflex by unconditioned stimulus
	Conditioned inhibition	Introduction of unknown (new) conditioned stimulus
	Inhibition by delay	Delay in applying unconditioned stimulus
	Differential inhibition	Alteration of conditioned stimulus

Food Avoidance Conditioning

If an animal is given a tasty food along with injection of a drug, which produces nausea or sickness, the animal starts avoiding or hating that food. It is called **food aversion conditioning.**

Conditioned Reward Reflex

If the animal is rewarded by a banana by pressing a bar, the animal repeatedly presses the bar. It is the conditioned reward reflex.

Instrumental conditioned reflexes play an important role during the learning processes of a child. These conditioned reflexes are also responsible for the behavior pattern of an individual.

■ PHYSIOLOGICAL BASIS OF CONDITIONED REFLEXES

Learning and memory form the physiological basis of conditioned reflexes.

■ SPEECH

■ DEFINITION

Speech is defined as the expression of thoughts by production of articulate sound, bearing a definite meaning. It is one of the highest functions of brain.

When a sound is produced verbally, it is called the speech. If it is expressed by visual symbols, it is known as writing. If visual symbols or written words are expressed verbally, that becomes reading.

■ MECHANISM OF SPEECH

Speech depends upon coordinated activities of central speech apparatus and peripheral speech apparatus. **Central speech apparatus** consists of higher centers, i.e. the cortical and subcortical centers. **Peripheral speech apparatus** includes larynx or sound box, pharynx, mouth, nasal cavities, tongue and lips. All the structures of peripheral speech apparatus function in coordination with respiratory system, with the influences of motor impulses from respective motor areas of the cerebral cortex.

■ DEVELOPMENT OF SPEECH

First Stage

First stage in the development of speech is the association of certain words with visual, tactile, auditory and other sensations, aroused by objects in the external world. Association of words with other sensations is stored as memory.

Second Stage

New neuronal circuits are established during the development of speech. When a definite meaning has been attached to certain words, pathway between the auditory area (Heschl area; area 41) and motor area for the muscles of articulation, which helps in speech (Broca area 44) is established. The child attempts to formulate and pronounce the learnt words.

Role of Cortical Areas in the Development of Speech

Development of speech involves integration of three important areas of cerebral cortex:
1. Wernicke area
2. Broca area
3. Motor area.

Role of Wernicke area – Speech understanding

Understanding of speech begins in Wernicke area that is situated in upper part of temporal lobe. It sends fibers to Broca area through a tract called arcuate fasciculus. Wernicke area is responsible for understanding the visual and auditory information required for the production of words. After understanding the words, it sends the information to Broca area.

Role of Broca area – Speech synthesis

Speech is synthesized in the Broca area. It is situated adjacent to the motor area, responsible for the movements of tongue, lips and larynx, which are necessary

for speech. By receiving information required for production of words from Wernicke area, the Broca area develops the pattern of motor activities required to verbalize the words. The pattern of motor activities is sent to motor area.

Role of motor area – Activation of peripheral speech apparatus

By receiving the pattern of activities from Broca area, motor area activates the peripheral speech apparatus. It results in initiation of movements of tongue, lips and larynx required for speech.

Later, when the child is taught to read, auditory speech is associated with visual symbols (area 18). Then, there is an association of the auditory and visual areas with the motor area for the muscles of hand. Now, the child is able to express auditory and visual impressions in the form of written words.

■ NERVOUS CONTROL OF SPEECH

Speech is an integrated and a well-coordinated motor phenomenon. So, many parts of cortical and subcortical areas are involved in the mechanism of speech.

Subcortical areas concerned with speech are controlled by cortical areas of dominant hemisphere. In about 95% of human beings, the left cerebral hemisphere is functionally dominant and those persons are right handed. Following are the motor and sensory cortical areas concerned with speech.

A. *Motor Areas*

1. *Broca area*

Broca area is also called **speech center,** motor speech area or lower frontal area. It includes areas 44 and 45. These areas are situated in lower part of lateral surface of prefrontal cortex.

Broca area controls the movements of structures (tongue, lips and larynx) involved in vocalization.

2. *Upper frontal motor area*

Upper frontal motor area is situated in paracentral gyrus over the medial surface of cerebral hemisphere. It controls the coordinated movements involved in writing.

B. *Sensory Areas*

1. *Secondary auditory area*

Secondary auditory area or auditopsychic area includes area 22. It is situated in the superior temporal gyrus. It is concerned with the **interpretation of auditory sensation** and storage of memories of spoken words.

2. *Secondary visual area*

Secondary visual area or **visuopsychic area** includes area 18. It is present in angular gyrus of the parietal cortex. This area is concerned with the **interpretation of visual sensation** and storage of memories of the visual symbols.

C. *Wernicke Area*

Wernicke area is situated in the upper part of temporal lobe. This area is responsible for the **interpretation of auditory sensation.** It also plays an important role in speech. It is responsible for understanding the auditory information about any word and sending the information to Broca area (Table 162.3).

■ APPLIED PHYSIOLOGY – DISORDERS OF SPEECH

Speech disorder is a communication disorder characterized by disrupted speech. It is of four types:

I. Aphasia
II. Anarthria or dysarthria
III. Dysphonia
IV. Stammering.

■ APHASIA

Aphasia is defined as the loss or impairment of speech due to brain damage (in Greek, aphasia = without speech). It is an acquired disorder and it is distinct from developmental disorders of speech or other speech disorders like dysarthria. Aphasia is not due to paralysis of muscles of articulation. It is due to damage of speech centers.

Damage of speech centers impairs the expression and understanding of spoken words. It also affects reading and writing. Speech function is localized to left hemisphere in most of the people.

Aphasia may be associated with other speech disorders, which also occur due to brain damage.

Causes for Aphasia

Usually aphasia occurs due to damage of one or more speech centers, which are situated in cerebral cortex (Table 162.4). Damage of speech centers occurs due to:

1. Stroke
2. Head injury
3. Severe blow to head
4. Cerebral tumors
5. Brain infections
6. Degenerative diseases.

TABLE 162.3: Role of cortical areas in control of speech

Cortical areas		Function
Motor areas	Broca area: Areas 44 and 45	Controls movement of structures involved in speech
	Upper frontal motor area	Controls movements involved in writing
Sensory areas	Secondary auditory area: Area 22	Concerned with interpretation of auditory sensation Concerned with storage of memories of spoken words
	Secondary visual area: Area 18	Concerned with interpretation of visual sensation Concerned with storage of memories of visual symbols
Wernicke area		Concerned with interpretation of auditory sensation Concerned with understanding auditory information and sending it to Broca area

TABLE 162.4: Features and causes of different types of aphasia

Type of aphasia	Features	Cause
Broca aphasia	Non-fluent speech problem	Lesion in left frontal lobe
Wernicke aphasia	Speech without any meaning	Lesion in left temporal lobe
Global aphasia	Combined features of Broca aphasia and Wernicke aphasia	Widespread lesion in speech areas of left cerebral hemisphere
Nominal aphasia	Inability to name the familiar objects	Lesion in posterior temporal and inferior parietal gyri
Motor aphasia	Difficulty in uttering individual words	Defect in pathway between left speech center and precentral cortex
Auditory aphasia	Inability to understand spoken words	Lesion in secondary auditory area
Visual aphasia	Inability to understand written symbols	Lesion in secondary visual area
Agraphia	Inability to write	Defect in pathway between cortical areas concerned with writing

Usually, in conditions like head injury, aphasia occurs suddenly and in conditions like infections or cerebral tumors, it develops slowly. In children, traumatic aphasia can develop by exposure to a horrifying event, without any brain damage. It may be cured with psychological treatment.

Types of Aphasia

Aphasia is classified by different methods. The simple and convenient clinical classification divides aphasia into five types:

1. Broca aphasia
2. Wernicke aphasia
3. Global aphasia
4. Nominal aphasia
5. Other types of aphasia.

1. *Broca aphasia*

Broca aphasia is the **non-fluent speech problem.** It occurs due to lesion in left frontal lobe of cerebral cortex. It is also known as expressive aphasia or anterior aphasia. The affected persons do not complete the sentences because of their inability to construct the sentences. They often talk in short phrases by omitting small words such as 'and', 'is', 'for', etc. They make great efforts even to initiate speech.

Persons with Broca aphasia are able to understand spoken or written words. Often, they are affected by weakness or paralysis of right arm or leg. It is due to damage of frontal lobe, which is also responsible for motor activities.

2. *Wernicke aphasia*

Wernicke aphasia is the speech without any meaning. It is also called receptive aphasia or posterior aphasia. Wernicke aphasia occurs due lesion in left temporal lobe. It is characterized by fluent speech. The affected persons speak long sentences but without any meaning. They use incorrect or non-existent words and cannot speak sensibly. This type of speech is known as jargon speech.

These individuals are unable to understand others' speech. Because of this weakness, they are unaware

of their own mistakes while speaking. Often, they are mistaken as psychiatric patients.

Wernicke aphasia is not associated with paralysis or weakness of muscles because, the injury does not involve the centers concerned with movements.

3. *Global aphasia*

Global aphasia is the type of aphasia characterized by combined features of Broca aphasia and Wernicke aphasia. It is due to widespread lesion in speech areas caused by infarction of left cerebral hemisphere. It is the most common type of aphasia. The affected persons can neither speak nor understand the spoken words. They cannot read and write also. So they have severe communication problems.

4. *Nominal aphasia*

Nominal aphasia is the speech disorder characterized by inability in naming the familiar objects. It is also called **anomic aphasia** or **amnesic aphasia.** It is due to lesion in posterior temporal and inferior parietal gyri.

5. *Other types of aphasia*

i. *Motor aphasia:* It is the speech disorder caused by the defect in the pathway between left speech areas and excitomotor or precentral cortex (Chapter 152). It is also known as **verbal aphasia** or **dyspraxia** or **apraxia of speech.** It is characterized by difficulty in uttering individual words due to lack of coordination between central speech apparatus (higher cortical centers) and peripheral speech apparatus. The affected persons are able to decide what to talk. But they cannot pronounce all the words. They are able to pronounce only few monosyllables such as 'yes' or 'no'.

ii. *Sensory aphasia:* It is the inability to understand words or symbols. It is of two types:
   a. *Auditory aphasia:* Inability to understand the spoken words. It is also called **word deafness.** It is due to the lesion in secondary auditory area.
   b. *Visual aphasia:* Inability to understand written symbols (difficulty in reading). It is also called **word blindness** or **dyslexia** and it occurs due to the lesion in secondary visual area.

iii. *Agraphia:* Agraphia means inability to write. There is no defect in the muscles of the hand concerned with writing. The subject can read and speak. Agraphia is due to the defect in the connection between the cortical areas concerned with writing. Agraphia differs from dysgraphia, which is characterized by distorted writing or writing incorrect letters.

Head's Classification of Aphasia

Henry Head was the pioneer scientist in the field of speech disorders and he was the first one to classify aphasia. In 1926, he classified aphasia into four types. Head's classification of aphasia is given in Table 162.5.

■ DYSARTHRIA OR ANARTHRIA

The term dysarthria refers to disturbed articulation. Anarthria means inability to speak. Dysarthria or anarthria is defined as the difficulty or inability to speak because of paralysis or ataxia of muscles involved in articulation. Psychic aspect of speech is not affected. The spoken and written words are understood.

Causes of Dysarthria

Dysarthria is caused by damage of brain or the nerves that control the muscles involved in speech. It occurs in conditions like stroke, brain injury, degenerative disease like Parkinson disease and Huntington disease.

■ DYSPHONIA

Dysphonia is a voice disorder. Often, it is characterized by hoarseness and a sore or a dry throat. Hoarseness means the difficulty in producing sound while trying to speak or a change in the pitch or loudness of voice. The voice may be weak, breathy, scratchy or husky.

Causes of Dysphonia

1. Trauma of vocal cords
2. Paralysis of vocal cords
3. Lumps (nodules) on vocal cords
4. Inflammation of larynx
5. Hypothyroidism
6. Stress (psychological dysphonia).

TABLE 162.5: Head's classification of aphasia

Type of aphasia	Features
Verbal aphasia	Inability in formation of words
Syntactical aphasia	Inability to arrange words in proper sequence
Semantic aphasia	Inability to recognize the significance of words
Nominal aphasia	Inability to name the familiar objects

■ STAMMERING

Stammering or **shuttering** is a speech disorder characterized by hesitations and involuntary repetitions of certain syllables or words. It is also described as a speech disorder in which normal flow of speech is disturbed by repetitions, prolongations or abnormal block or stoppage of sound and syllables. It is due to the neurological incoordination of speech and it is common in children.

Stammering is associated with some unusual facial and body movements. Exact cause for stammering is not known. It is thought that stammering may be due to genetic factors, brain damage, neurological disorders or anxiety.

Cerebrospinal Fluid (CSF)

Chapter 163

- INTRODUCTION
- PROPERTIES AND COMPOSITION
- FORMATION
  - SITE OF FORMATION
  - MECHANISM OF FORMATION
  - SUBSTANCES AFFECTING THE FORMATION
- CIRCULATION
- ABSORPTION
- PRESSURE EXERTED
- FUNCTIONS
- COLLECTION
  - LUMBAR PUNCTURE
- BLOOD-BRAIN BARRIER
  - STRUCTURE
  - FUNCTIONS
- BLOOD-CEREBROSPINAL FLUID BARRIER
- APPLIED PHYSIOLOGY – HYDROCEPHALUS

INTRODUCTION

Cerebrospinal fluid (CSF) is the clear, colorless and transparent fluid that circulates through **ventricles** of brain, **subarachnoid space** and **central canal** of spinal cord. It is a part of extracellular fluid (ECF).

PROPERTIES AND COMPOSITION OF CEREBROSPINAL FLUID

Properties

Volume	:	150 mL (100 mL to 200 mL)
Rate of formation	:	0.3 mL per minute
Specific gravity	:	1.005
Reaction	:	Alkaline.

Composition

Composition of CSF is given in Figure 163.1. Since CSF is a part of ECF, it contains more amount of sodium than potassium. CSF also contains some lymphocytes. CSF secreted by ventricle does not contain any cell. Lymphocytes are added when CSF flows in the spinal cord.

FORMATION OF CEREBROSPINAL FLUID

SITE OF FORMATION

CSF is formed by **choroid plexuses,** situated within the ventricles. Choroid plexuses are tuft of capillary projections present inside the ventricles and are covered by pia mater and ependymal covering. A large amount of CSF is formed in the lateral ventricles.

MECHANISM OF FORMATION

CSF is formed by the process of **secretion** that involves **active transport mechanism.** Formation of CSF does not involve ultrafiltration or dialysis.

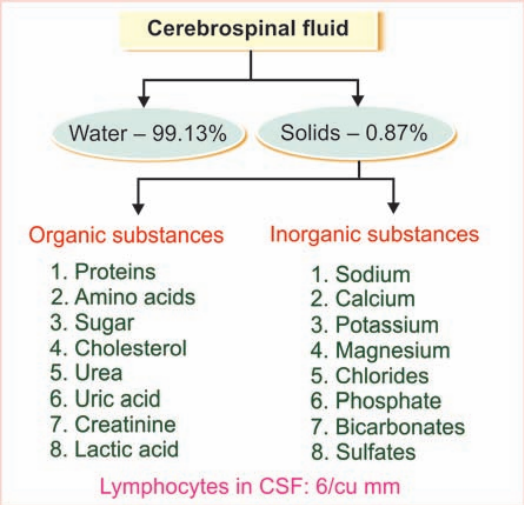

FIGURE 163.1: Composition of cerebrospinal fluid

■ SUBSTANCES AFFECTING THE FORMATION OF CSF

1. Pilocarpine, ether and extracts of pituitary gland stimulate the secretion of CSF by stimulating choroid plexus
2. Injection of isotonic saline also stimulates CSF formation
3. Injection of hypotonic saline causes greater rise in capillary pressure and intracranial pressure and fall in osmotic pressure, leading to increase in CSF formation
4. Hypertonic saline decreases CSF formation and decreases the CSF pressure. The increased intracranial pressure is reduced by injection of 30% to 35% of sodium chloride or 50% sucrose.

■ CIRCULATION OF CEREBROSPINAL FLUID

Major quantity of CSF is formed in **lateral ventricles** and enters third ventricle by passing through **foramen of Monro** (Figs. 163.2 and 163.3). From here, it passes to **fourth ventricle** through **aqueductus Sylvius.** From fourth ventricle, CSF enters the **cisterna magna** and **cisterna lateralis** through **foramen of Magendie** (central opening) and **foramen of Luschka** (lateral opening).

From cisterna magna and cisterna lateralis, CSF circulates through **subarachnoid space** over spinal cord and cerebral hemispheres. It also flows into **central canal** of spinal cord.

■ ABSORPTION OF CEREBROSPINAL FLUID

CSF is mostly absorbed by the **arachnoid villi** into **dural sinuses** and **spinal veins.** Small amount is absorbed along the **perineural spaces** into **cervical lymphatics** and into the **perivascular spaces.**

The mechanism of absorption is by filtration due to pressure gradient between hydrostatic pressure in the subarachnoid space fluid and the pressure that exists in the dural sinus blood. Colloidal substances pass slowly and crystalloids are absorbed rapidly.

Normally, about 500 mL of CSF is formed everyday and an equal amount is absorbed.

■ PRESSURE EXERTED BY CEREBROSPINAL FLUID

Pressure exerted by CSF in man varies in different position, viz.

Lateral recumbent position : 10 to 18 cm of H_2O
Lying position : 13 cm of H_2O
Sitting position : 30 cm of H_2O

Certain events like coughing and crying increase the pressure by decreasing absorption. Compression of internal jugular vein also raises the CSF pressure.

■ FUNCTIONS OF CEREBROSPINAL FLUID

1. *Protective Function*

CSF acts as fluid buffer and protects the brain from shock. Since, the specific gravity of brain and CSF is more or less same, brain floats in CSF. When head receives a blow, CSF acts like a cushion and prevents the movement of brain against the skull bone and thereby, prevents the damage of brain.

However, if the head receives a severe blow, the brain moves forcefully and hits against the skull bone, leading to the damage of brain tissues. Brain strikes against the skull bone at a point opposite to the point where the blow was applied. So, this type of damage to the brain is known as **countercoup injury.**

2. *Regulation of Cranial Content Volume*

Regulation of cranial content volume is essential because, brain may be affected if the volume of cranial content increases. It happens in cerebral hemorrhage and brain tumors.

Increase in cranial content volume is prevented by greater absorption of CSF to give space for the increasing cranial contents.

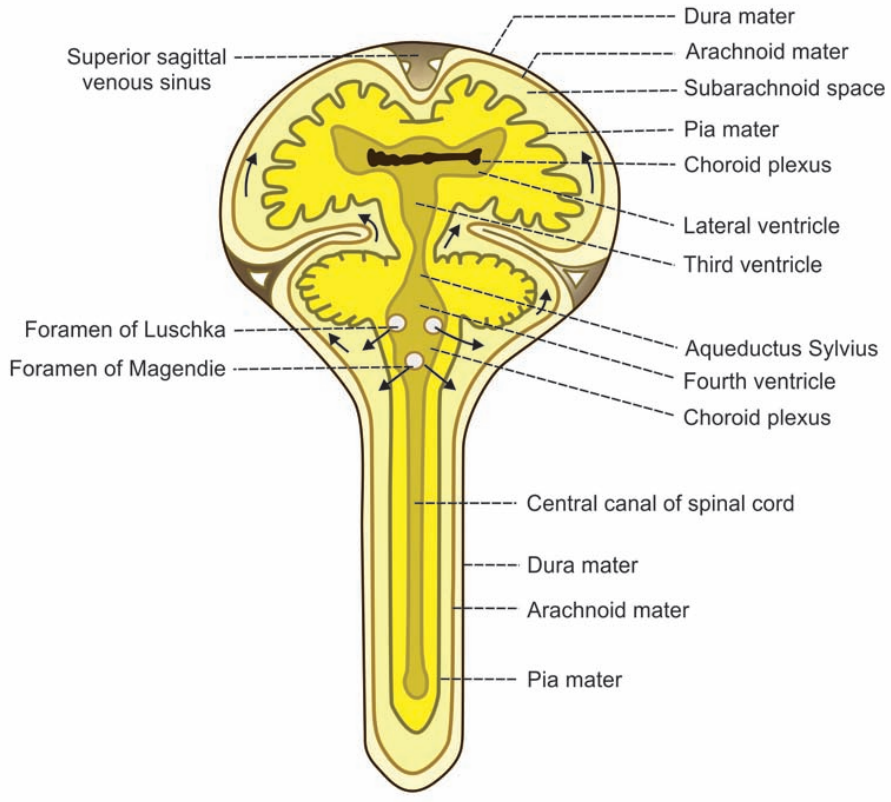

FIGURE 163.2: Circulation of cerebrospinal fluid

3. *Medium of Exchange*

CSF is the medium through which many substances, particularly nutritive substances and waste materials are exchanged between blood and brain tissues.

■ COLLECTION OF CEREBROSPINAL FLUID

CSF is collected either by **cisternal puncture** or **lumbar puncture.** In cisternal puncture, the CSF is collected by passing a needle between the occipital bone and atlas, so that it enters cisterna magna. In lumbar puncture, the lumbar puncture needle is introduced into subarachnoid space in lumbar region, between the third and fourth lumbar spines.

■ LUMBAR PUNCTURE

Posture of Body for Lumbar Puncture

The reclining body is bent forward, so as to flex the vertebral column as far as possible. Then the body is brought near edge of a table. The highest point of iliac crest is determined by palpation. A line is drawn on the back of the subject by joining the highest points of **iliac crests** of both sides. Opposite to midplane, this line crosses the fourth lumbar spine.

After determining the area of fourth lumbar spine, third lumbar spine is palpated. The needle is introduced into subarachnoid space by passing through soft tissue space between the two spines.

Reasons for selecting this site

1. Spinal cord will not be injured, because, it terminates below the lower border of the first lumbar vertebra. Cauda equina may be damaged. But it is regenerated.
2. Subarachnoid space is wider in this site. It is because the pia mater is reduced very much.

Uses of Lumbar Puncture

Lumbar puncture is used for:

1. Collecting CSF for diagnostic purposes
2. Injecting drugs (intrathecal injection) for spinal anesthesia, analgesia and chemotherapy
3. Measuring the pressure exerted by CSF.

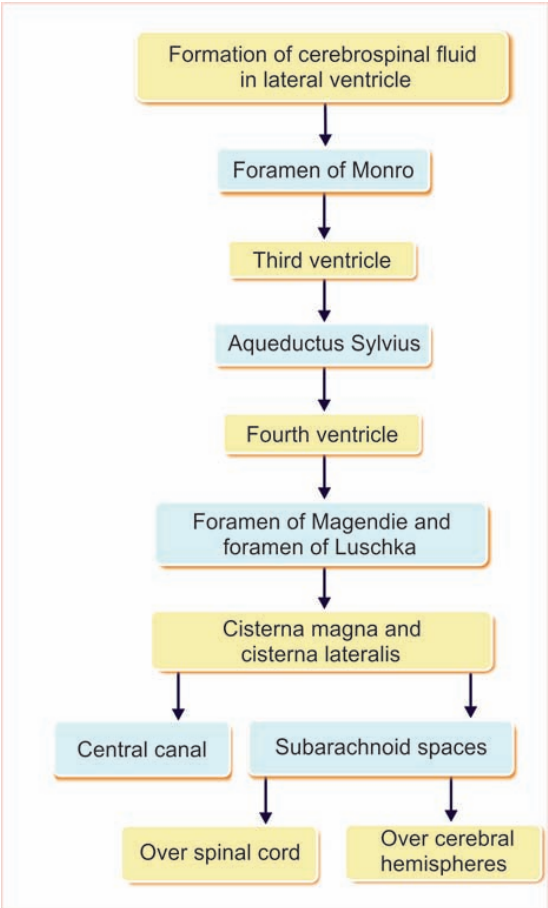

FIGURE 163.3: Cerebrospinal fluid circulation

■ BLOOD-BRAIN BARRIER

Blood-brain barrier (BBB) is a neuroprotective structure that prevents the entry of many substances and pathogens into the brain tissues from blood.

It was observed more than 50 years ago, that when **trypan blue,** the acidic dye was injected into living animals, all the tissues of body were stained by it, except the brain and spinal cord. This observation suggested that there was a hypothetical barrier, which prevented the diffusion of trypan blue into the brain tissues from the capillaries. This barrier was named as blood-brain barrier (BBB). It exists in the capillary membrane of all parts of the brain, except in some areas of hypothalamus.

■ STRUCTURE OF BLOOD-BRAIN BARRIER

Tight junctions in the endothelial cells of brain capillaries are responsible for BBB mechanism.

In capillaries of other organs, adjacent endothelial cells leave the cleft called **fenestra,** which allows **transcytosis** of several substances through endothelium (Chapter 111). However, in capillaries of brain, fenestra are absent because, the endothelial cells fuse with each other by tight junctions (Fig. 163.4).

Tight junctions are formed between endothelial cells of the capillaries at childhood. At the same time, cytoplasmic foot processes of astrocytes (neuroglial cells) develop around capillaries and reinforce the barrier. Astocytes envelop the vasculature almost completely.

Pericytes also form the important cellular constituent of BBB. These cells play an important role in formation and maintenance of tight junction and structural stability of the barrier. In brain, pericytes function as macrophages and play an important role in the defense.

■ FUNCTIONS OF BLOOD-BRAIN BARRIER

BBB acts as both a mechanical barrier and transport mechanisms. It prevents potentially harmful chemical substances and permits metabolic and essential materials into the brain tissues. By preventing injurious materials and organisms, BBB provides healthy environment for the nerve cells of brain.

Substances which can Pass through Blood-Brain Barrier

1. Oxygen
2. Carbon dioxide
3. Water
4. Glucose
5. Amino acids
6. Electrolytes
7. Drugs such as L-dopa, 5-hydroxytryptamine sulfonamides, tetracycline and many lipid-soluble drugs
8. Lipid-soluble anesthetic gases such as ether and nitrous oxide
9. Other lipid-soluble substances.

Substances which cannot Pass through Blood-Brain Barrier

1. Injurious chemical agents
2. Pathogens such as bacteria
3. Drugs such as Penicillin and the catecholamines. Dopamine also cannot pass through BBB. So, parkinsonism is treated with L-dopa, instead of dopamine.

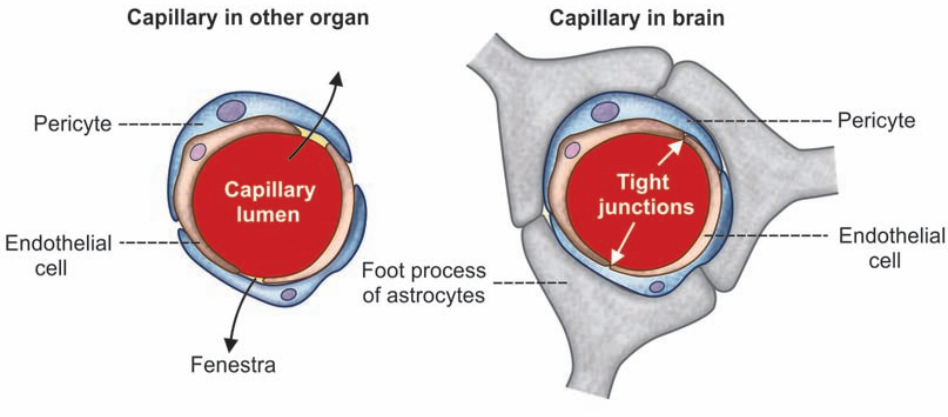

FIGURE 163.4: Blood-brain barrier

4. Bile pigments: However, since the barrier is not well developed in infants, the bile pigments enter the brain tissues. During **jaundice** in infants, the bile pigments enter brain and causes damage of **basal ganglia,** leading to **kernicterus** (refer Chapter 21 for details).

■ BLOOD-CEREBROSPINAL FLUID BARRIER

Blood-CSF barrier is the barrier between blood and cerebrospinal fluid that exists at the choroid plexus. The function of this barrier is similar to that of BBB. It does not allow the movement of many substances from blood to cerebrospinal fluid. It allows the movement of only those substances which are allowed by BBB.

■ APPLIED PHYSIOLOGY – HYDROCEPHALUS

Abnormal accumulation of CSF in the skull, associated with enlargement of head is called hydrocephalus. During obstruction of any foramen, through which CSF escapes, the ventricular cavity dilates and this condition is called **internal hydrocephalus.** It is also known as **non-communicating** hydrocephalus.

On the other hand, if the arachnoid villi are blocked, **external** or **communicating hydrocephalus** occurs.

Hydrocephalus along with increased intracranial pressure causes headache and vomiting. In severe conditions, it leads to atrophy of brain, mental weakness and convulsions.

Autonomic Nervous System (ANS)

Chapter 164

- INTRODUCTION
- SYMPATHETIC DIVISION
- PARASYMPATHETIC DIVISION
- FUNCTIONS
- NEUROTRANSMITTERS
- SYMPATHOMIMETIC DRUGS
- SYMPATHETIC BLOCKERS
- PARASYMPATHOMIMETIC DRUGS
- PARASYMPATHETIC BLOCKERS
- GANGLIONIC BLOCKERS

INTRODUCTION

Autonomic nervous system (ANS) is primarily concerned with regulation of visceral or vegetative functions of the body. So, it is also called **vegetative** or **involuntary nervous system.**

DIVISIONS OF ANS

From anatomical and physiological point of view, ANS is divided into two divisions:

1. Sympathetic division
2. Parasympathetic division.

Differences and comparison between both the divisions of ANS are given in Tables 164.1 and 164.2.

SYMPATHETIC DIVISION

Sympathetic division is otherwise called **thoracolumbar outflow** because, the preganglionic neurons are situated in lateral gray horns of 12 thoracic and first two lumbar segments of spinal cord. Fibers arising from here are known as preganglionic fibers. Preganglionic fibers leave the spinal cord through anterior nerve root and white rami communicantes and terminate in the postganglionic neurons, which are situated in the sympathetic ganglia.

Sympathetic division supplies smooth muscle fibers of all the visceral organs such as blood vessels, heart, lungs, glands, gastrointestinal organs, etc.

SYMPATHETIC GANGLIA

Ganglia of sympathetic division are classified into three groups:

A. Paravertebral or sympathetic chain ganglia
B. Prevertebral or collateral ganglia
C. Terminal or peripheral ganglia.

A. *Paravertebral or Sympathetic Chain Ganglia*

Paravertebral or sympathetic chain ganglia are arranged in a segmental fashion along the anterolateral surface of vertebral column. Ganglia on either side of the spinal cord are connected with each other by longitudinal fibers, to form the **sympathetic chains** (Fig. 164.1). Both the chains extend from skull to coccyx.

Ganglia of the sympathetic chain (trunk) on each side are divided into four groups:

1. Cervical ganglia : 8 in number
2. Thoracic ganglia : 12 in number
3. Lumbar ganglia : 5 in number
4. Sacral ganglia : 5 in number.

TABLE 164.1: Actions of sympathetic and parasympathetic divisions of autonomic nervous system

Effector organ		Sympathetic division	Parasympathetic division
1. Eye	Ciliary muscle	Relaxation	Contraction
	Pupil	Dilatation	Constriction
2. Lacrimal glands		Decrease in secretion	Increase in secretion
3. Salivary glands		Decrease in secretion and vasoconstriction	Increase in secretion and vasodilatation
4. Gastrointestinal tract	Motility	Inhibition	Acceleration
	Secretion	Decrease	Increase
	Sphincters	Constriction	Relaxation
	Smooth muscles	Relaxation	Contraction
5. Gallbladder		Relaxation	Contraction
6. Urinary bladder	Detrusor muscle	Relaxation	Contraction
	Internal sphincter	Constriction	Relaxation
7. Sweat glands		Increase in secretion	–
8. Heart – rate and force		Increase	Decrease
9. Blood vessels		Constriction of all blood vessels, except those in heart and skeletal muscle	Dilatation
10. Bronchioles		Dilatation	Constriction

1. *Cervical ganglia*

Eight cervical ganglia are arranged in three groups:

i. *Superior cervical ganglion:* It is formed by the fusion of upper four cervical ganglia. It is the largest ganglion of ANS. It receives preganglionic fibers from first thoracic spinal segment (T1) via white rami. Postganglionic fibers from this ganglion, supply the blood vessels, glands, etc. Superior cervical ganglion also sends some fibers to heart through superior cervical sympathetic nerve and cardiac plexus.

ii. *Middle cervical ganglion:* It is formed by fifth and sixth cervical ganglia. Preganglionic fibers arise from T1 segment. Postganglionic fibers from here supply the sweat glands, thyroid gland and parathyroid glands. It also sends fibers to heart via middle cervical sympathetic nerve and cardiac plexus.

iii. *Inferior cervical ganglion:* This ganglion is formed by the fusion of seventh and eighth cervical ganglia. First thoracic ganglion fuses with inferior cervical ganglion, forming stellate ganglion. It receives preganglionic fibers from T1 segment. It sends postganglionic fibers to heart through inferior cervical sympathetic nerve and cardiac plexus. Postganglionic fibers also form the plexus around subclavian artery and its branches.

2. *Thoracic ganglia*

There are 12 thoracic ganglia on each side and these ganglia are evenly spaced. Thoracic ganglia receive preganglionic fibers from the thoracic segments of spinal cord. Postganglionic fibers from thoracic ganglia are distributed to **visceral organs** in the **thorax** and **abdomen.**

3. *Lumbar ganglia*

There are 5 lumbar ganglia. Preganglionic fibers for these ganglia arise from first and second lumbar spinal segments (L1 and L2) and reach the lumbar ganglia. From here, the fibers extend down to sacral ganglia also. Postganglionic fibers from these ganglia supply the abdominal and **pelvic organs.**

4. *Sacral ganglia*

There are 5 sacral ganglia, which receive the preganglionic fibers from L1 and L2 segments. Postganglionic fibers from sacral ganglia innervate the **blood vessels** and **sweat glands** in the lower limb.

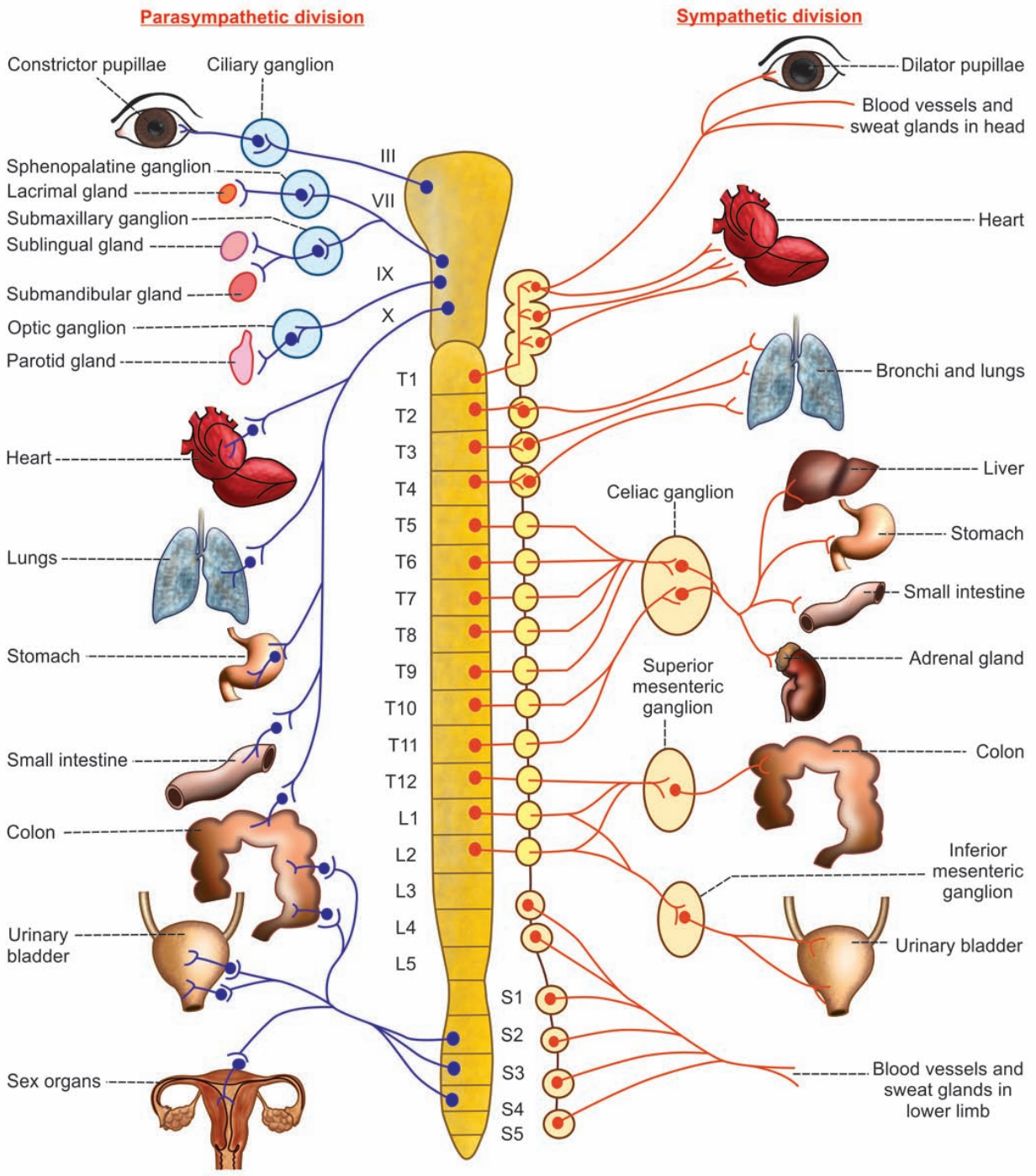

FIGURE 164.1: Autonomic nervous system

TABLE 164.2: Classical comparison of sympathetic and parasympathetic divisions of autonomic nervous system

Features	Sympathetic division	Parasympathetic division
1. Location of preganglionic neuron	Thoracolumbar segments of spinal cord	Nuclei of III, VII, IX and X cranial nerves and sacral (S2 to S4) segments of spinal cord
2. Location of postganglionic neuron	Away from target organ	Near or in the target organ
3. Length of preganglionic fibers	Relatively short	Relatively long
4. Length of postganglionic fibers	Relatively long	Relatively short
5. Preganglionic neurotransmitter	Acetylcholine	Acetylcholine
6. Postganglionic neurotransmitter	Noradrenaline	Acetylcholine

Below the sacral level, both the sympathetic trunks converge and fuse upon the anterior surface of coccyx and form a terminal swelling. This terminal swelling is known as **coccygeal ganglion.** Unpaired coccygeal ganglion is also called **ganglion impar.** It receives preganglionic fibers from L1 and L2 segments. Postganglionic fibers from here are distributed to the abdominal viscera and pelvic region.

B. *Prevertebral or Collateral Ganglia*

Prevertebral ganglia are situated in thorax, abdomen and pelvis, in relation to aorta and its branches.

Prevertebral ganglia are:

1. Celiac ganglion
2. Superior mesenteric ganglion
3. Inferior mesenteric ganglion.

Prevertebral ganglia receive preganglionic fibers from T5 to L2 segments. Postganglionic fibers from these ganglia supply the visceral organs of thorax, abdomen and pelvis.

C. *Terminal or Peripheral Ganglia*

Terminal ganglia are situated within or close to structures innervated by them. Heart, bronchi, pancreas and urinary bladder are innervated by the terminal ganglia.

Sympathoadrenergic System

Sympathoadrenergic system is a functional and phylogenetic unit that includes sympathetic division and adrenal medulla. Adrenal medulla is a modified sympathetic ganglion. Since adrenal medulla and sympathetic division develop from the same neural crest, their secretions and functions are almost the same. Any increase in sympathetic activity increases the secretion of catecholamines from adrenal medulla (refer Chapter 71).

■ PARASYMPATHETIC DIVISION

Parasympathetic division of ANS is otherwise called the **craniosacral outflow** because, the fibers of this division arise from brain and sacral segments of spinal cord.

■ CRANIAL OUTFLOW OR CRANIAL PORTION OF PARASYMPATHETIC DIVISION

Cranial outflow or cranial portion of parasympathetic division arises from brainstem. It innervates the blood vessels of head and neck and many thoracoabdominal visceral organs. Cranial outflow includes the following cranial nerves:

1. Oculomotor (III) nerve
2. Facial (VII) nerve
3. Glossopharyngeal (IX) nerve
4. Vagus (X) nerve.

Preganglionic fibers of these cranial nerves arise from neurons situated at two different levels:

1. Tectal or midbrain outflow (III cranial nerve)
2. Bulbar level or bulbar outflow (VII, IX and X cranial nerves).

Preganglionic fibers are longer and reach the postganglionic neurons, which are situated within the organs or close to the organs innervated by these nerves. Preganglionic fibers are myelinated, but the postganglionic fibers are non-myelinated.

1. *Tectal or Midbrain Outflow*

Group of cells forming **Edinger-Westphal nucleus** of III cranial nerve gives rise to tectal fibers. Fibers from this nucleus end in ciliary ganglion. Postganglionic fibers from here supply the sphincter pupillae and ciliary muscle.

2. *Bulbar Level or Bulbar Outflow*

Preganglionic fibers are the fibers of VII, IX and X cranial nerves, which arise from the nuclei present in the medulla oblongata.

Fibers of VII cranial nerve supply the lacrimal, nasal, submaxillary and sublingual glands. Preganglionic fibers of this nerve end in sphenopalatine ganglion and submaxillary ganglion. Postganglionic fibers from sphenopalatine ganglion supply lacrimal and nasal glands. Postganglionic fibers from submaxillary ganglion supply sublingual and submaxillary glands.

Fibers of IX cranial nerve supply the parotid gland. Preganglionic fibers synapse with neurons of otic ganglion. Postganglionic fibers from otic ganglion supply the parotid gland.

Fibers of X cranial nerve supply visceral organs of the body. Preganglionic fibers terminate in the ganglia, which are situated on or near the organs. Postganglionic fibers from the ganglia supply the organs. Vagus nerve supplies almost all the organs in the thorax and abdomen, but not the pelvic organs.

■ SACRAL OUTFLOW OR SACRAL PORTION OF PARASYMPATHETIC DIVISION

Sacral outflow or sacral portion of parasympathetic division arises from the sacral segments of spinal cord. It innervates smooth muscles forming the walls of viscera and the glands such as large intestine, liver, spleen, kidneys, bladder, genitalia, etc.

Preganglionic fibers arise from anterior gray horn cells of 2nd, 3rd and 4th (from 1st also in some cases) sacral segments of spinal cord and form the pelvic nerve (nervi erigens). Fibers end on postganglionic neurons, which are situated on or near the visceral organs. Fibers from postganglionic neurons supply descending colon, rectum, urinary bladder, internal sphincter, urethra and accessory sex organs.

Sacral parasympathetic fibers supply those visceral organs which are not supplied by vagus.

■ FUNCTIONS OF ANS

Autonomic nervous system is concerned with the regulation of functions, which are beyond voluntary control. By controlling the various vegetative functions, ANS plays an important role in maintaining constant internal environment (homeostasis).

Almost all the visceral organs are supplied by both sympathetic and parasympathetic divisions of ANS and the two divisions produce antagonistic effects on each organ. When the fibers of one division supplying to an organ is sectioned or affected by lesion, the effects of fibers from other division on the organ become more prominent.

Actions of the sympathetic and parasympathetic fibers on various structures are given in Table 164.1.

■ NEUROTRANSMITTERS OF ANS

Different nerve fibers of ANS execute the functions by releasing some neurotransmitter substances (Table 164.2).

■ SYMPATHETIC FIBERS

1. *Preganglionic fibers:* Acetylcholine (Ach)
2. *Postganglionic noradrenergic fibers:* Noradrenaline
3. *Postganglionic cholinergic fibers:* Ach

Postganglionic sympathetic cholinergic nerve fibers supply sweat glands and blood vessels in heart and in skeletal muscle.

■ PARASYMPATHETIC FIBERS

1. Preganglionic fibers: Ach
2. Postganglionic fibers: Ach

Catecholamines

Synthesis and the metabolism of catecholamines are explained in Chapter 71.

Acetylcholine

Refer Chapter 141 for details of acetylcholine.

Receptors of Neurotransmitter

Adrenergic receptors: Details are given in Chapter 71.
Acetylcholine receptors: Details are given in Chapter 141.

■ SYMPATHOMIMETIC DRUGS

Sympathomimetic drugs or **adrenaline-like** drugs are the drugs, which produce the effects of sympathetic stimulation. Adrenaline and noradrenaline produced in the body act only for a short duration of about 1 to 2 minutes. Whereas, sympathomimetic drugs injected intravenously act for a longer period of about 30 minutes to 2 hours. Sympathomimetic drugs are:

Drugs Stimulating the Receptors Directly

1. Phenylephrine (alpha receptors)
2. Isoproterenol (beta receptors)
3. Albuterol (beta-2 receptors).

Drugs Inducing the Release of Noradrenaline

1. Ephedrine
2. Tyramine
3. Amphetamine.

■ SYMPATHETIC BLOCKERS

Sympathetic blockers are the drugs that prevent actions of sympathetic neurotransmitter. Sympathetic blockers act on all levels. Actions of blocking agents are given in Table 164.3.

TABLE 164.3: Actions of sympathetic blocking agents

Blocking agent	Action
1. Reserpine	Prevention of synthesis and storage of noradrenaline
2. Quanethidine	Prevention of release of noradrenaline
3. Phenoxybenzamine	Blockage of alpha adrenergic receptors
4. Phentolamine	Blockage of alpha adrenergic receptors
5. Metaprolal	Blockage of beta adrenergic receptors
6. Hexamethonium	Blockage of transmission of nerve impulse through sympathetic ganglia

■ PARASYMPATHOMIMETIC DRUGS

Parasympathomimetic drugs or Ach-like drugs are drugs, which produce the effects of parasympathetic stimulation. Ach produced in the body acts only for a short period, whereas the injected Ach acts for a long time. Similarly, parasympathomimetic drugs also exhibit their actions for a longer time. Parasympathomimetic drugs are:

1. *Drugs which Act on Muscarinic Receptors*

Pilocarpine and **methacholine** produce their effects by acting on the **muscarinic receptors.**

2. *Drugs which Prolong the Action of Ach*

Action of Ach can be prolonged by preventing its destruction. Drugs like **neostigmine** and **physostigmine** inhibit the activity of acetylcholinesterase and so the Ach is not destroyed quickly.

■ PARASYMPATHETIC BLOCKERS

Parasympathetic blockers are drugs, which prevent the actions of parasympathetic neurotransmitter. The drugs atropine, homatropine and scopolamine inhibit the actions of Ach by blocking the muscarinic receptors.

■ GANGLIONIC BLOCKERS

Ganglionic blockers are the drugs that prevent the transmission of impulses from preganglionic neurons to postganglionic neurons. Tetraethyl ammonium ion, hexamethonium ion and pentolinium are some of the ganglionic blockers. These drugs block both sympathetic and parasympathetic ganglia. However, ganglionic blockers are commonly used to block sympathetic ganglia, rather than the parasympathetic ganglia because sympathetic blockade overshadows the parasympathetic blockade.

QUESTIONS IN NERVOUS SYSTEM

LONG QUESTIONS

1. What is neuron? Describe the structure of neuron and the properties of nerve fibers.
2. What are receptors? Classify them and explain their properties.
3. What is synapse? Explain the structure, functions and properties of synapse.
4. Define and classify reflex action. Explain reflex arc and the properties of reflexes.
5. Name the ascending tracts of the spinal cord and explain spinothalamic tracts.
6. What are the tracts of spinal cord? Describe the spinocerebellar tracts.
7. Give an account of tracts in the posterior white funiculus of spinal cord.
8. Enumerate the descending tracts of spinal cord. Describe in detail the pyramidal tracts. Write a note on the effects of upper and lower motor neuron lesions.
9. Write in detail, about the effects of complete and incomplete transection of spinal cord.
10. What are the thalamic nuclei? Describe the connections, functions and effects of lesions of thalamus.
11. Name the hypothalamic nuclei. Explain the connections, functions and effects of lesions of hypothalamus.
12. Explain the different parts of cerebellum? Enumerate the functions of cerebellum. Write a note on cerebellar lesions.
13. Explain the connections, functions and effects of lesions of corticocerebellum (neocerebellum).
14. Explain the connections, functions and effects of lesions of spinocerebellum (paleocerebellum).
15. Explain the connections, functions and effects of lesions of vestibulocerebellum (archicerebellum).
16. What are the components of basal ganglia? Give an account of connections, functions and disorders of basal ganglia.
17. What are the various lobes of cerebral cortex? Describe their functions. Add a note on frontal lobe syndrome.
18. Classify the components of limbic system. Explain the functions of limbic system.
19. What is reticular formation? Describe the connections and the functions of reticular formation.
20. Give an account of postural reflexes.
21. Explain the role of vestibular apparatus in the maintenance of equilibrium.

SHORT QUESTIONS

1. Structure of neuron.
2. Myelin sheath.
3. Neurotrophins.
4. Nerve growth factor.
5. Classification of nerve fibers.
6. Properties of nerve fibers.
7. Action potential in nerve fiber.
8. Voltage clamping.
9. Saltatory conduction.
10. Degeneration of nerve fiber.
11. Wallerian degeneration.
12. Regeneration of nerve fiber.
13. Neuroglia.
14. Exteroceptors.
15. Mechanoceptors.
16. Generator (receptor) potential.
17. Sensory transduction.
18. Synapse.
19. Synaptic transmission.
20. Synaptic inhibition/IPSP.
21. Synaptic potentials/EPSP.
22. Neurotransmitters.
23. Neuromodulators.
24. Opioid peptides.
25. Reflex arc.
26. Properties of reflexes.
27. Superficial reflexes.
28. Deep reflexes.
29. Babinski sign.
30. Spinothalamic tracts.
31. Spinocerebellar tracts.
32. Tracts of Goll and Burdach.
33. Pyramidal tracts.
34. Extrapyramidal tracts.
35. Upper motor neuron lesion.
36. Lower motor neuron lesion.
37. Complete transection of spinal cord.
38. Incomplete transection of spinal cord.
39. Brown-Sèquard syndrome/Hemisection of spinal cord.
40. Syringomyelia.
41. Tabes dorsalis.
42. Pathway for fine touch sensations.
43. Pathway for pressure sensation.
44. Pathway for temperature sensations.
45. Pathway for conscious kinesthetic sensations.
46. Pathway for subconscious kinesthetic sensations.
47. Pathway for pain sensations.

48. Pain sensation.
49. Referred pain.
50. Gate theory.
51. Functions of thalamus.
52. Thalamic lesions.
53. Internal capsule.
54. Functions of hypothalamus.
55. Regulation of food intake.
56. Disorders of hypothalamus.
57. Rage and sham rage.
58. Corticocerebellum (neocerebellum).
59. Spinocerebellum (paleocerebellum).
60. Corpus striatum.
61. Red nucleus.
62. Functions of basal ganglia.
63. Effects of lesions of basal ganglia.
64. Parkinson disease.
65. Prefrontal lobe of cerebral cortex.
66. Motor areas of cerebral cortex.
67. Frontal lobe of cerebral cortex.
68. Parietal lobe (or sensory areas) of cerebral cortex.
69. Frontal lobe syndrome.
70. Klüver-Bucy syndrome.
71. Localization of cortical connections.
72. Papez circuit.
73. Functions of limbic system.
74. ARAS.
75. Decerebrate rigidity.
76. Proprioceptors.
77. Muscle spindle.
78. Stretch reflex.
79. Reciprocal innervation.
80. Crossed extensor reflex.
81. Clasp-knife reflex.
82. Righting reflexes.
83. Semicircular canal.
84. Otolith organ.
85. Crista ampullaris.
86. Effects of stimulation of semicircular canals.
87. Nystagmus.
88. Motion sickness.
89. EEG.
90. Epilepsy.
91. EEG pattern during sleep.
92. Physiological changes during sleep.
93. REM and non-REM sleep.
94. Sleep disorders.
95. Learning.
96. Memory.
97. Classical conditioned reflexes.
98. Properties of conditioned reflexes.
99. Speech.
100. Speech disorders.
101. Aphasia.
102. CSF.
103. Blood-brain barrier.
104. Craniosacral outflow.
105. Thoracolumbar outflow.
106. Role of ANS in the regulation of cardiovascular functions.
107. Role of ANS in the regulation of gastrointestinal activity.
108. Neurotransmitters of ANS.
109. Functions of sympathetic division of ANS.
110. Functions of parasympathetic division of ANS.